# AN ECONOMIC ANALYSIS OF THE IMPACT OF REMOVING ORGANIC WASTE FROM SMALL SCALE CAGE AQUACULTURE SYSTEMS IN IRRIGATION DAMS IN THE WESTERN CAPE

by

**TICHAONA GUMBO**

*Thesis presented in partial fulfilment of the requirements of the degree of Master of Science in Agriculture in the Faculty of Agrisciences at the University of Stellenbosch*

Supervisor: Dr. JP Lombard

March 2011

**DECLARATION**

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: . . . . . . . . . . . . . . . . . .

## ABSTRACT

The rising demand of fish due to population growth coupled by stagnation of fish supply from natural capture has led the world to turn to aquaculture to fill in the gap between fish supply and demand. Aquaculture has emerged as the only sustainable way of supplying the rising population with fish. However the rapid expansion of aquaculture has been met with growing concerns over its environmental effects especially waste produced from aquaculture. The net cage system that is currently being used by small scale trout farmers in the Western Cape is an open water based system where release of waste into the water bodies is inevitable and this put into question the long term sustainability of trout farming using net cages in irrigation dams in the Western Cape.

This study sought to compare identified production techniques that can be used by aquaculture farmers to reduce accumulation of organic waste in irrigation dams. The proposed 'clean' production techniques include use of net cages fitted with Lift-up system, semi intensive floating tank system (SIFTS) and intergrated aquaculture systems. The study revealed that the intergrated aquaculture system is the most effective way of recovering waste that shows great potential of moving aquaculture towards long term sustainability as it fullfills sustainability dimensions such as 'zero emission', nutrient recycling and integrated production. Mechanical methods of recovering waste such as Lift-up system and SIFTS are also effective in recovering particulate waste but however dissolved nutrients are lost into the environment.

The study went on further to investigate if economic, environmental and social benefits of recovering waste from irrigation dams outweigh the costs of recovering waste using different production techniques. Models of small scale aquaculture farms using the three identified production techniques were developed and compared with a modelled small scale net cage farm where there was no waste recovery. A comparative financial analysis of the modelled small scale trout farms using alternative production techniques carried out showed that trout production using any of the three alternative 'clean' production techniques is financially viable with the SIFTS production technique giving the farmer the highest returns, followed by the intergrated system, then the net cage with a Lift-up system and lastly the net cage system without waste recovery.

The second part of the study used the contingent valuation method to estimate the environmental and social benefits of removing waste from dams. Households revealed that they were willing to pay (WTP) R40 on average annually to improve water quality from a state where eutrophication had occurred to a state suitable for irrigation and aquaculture. To improve water quality from a state suitable for irrigation to a state suitable for swimming, households were willing to pay R16.67

annually. If water was to be improved from a state suitable for irrigation to a level suitable for domestic purposes, average willingness to pay (WTP) was R26.17 annually. WTP indicate that besides financial benefits associated with using ‘clean’ production techniques there are environmental and social benefits that will arise to the farm community using water from the irrigation dams.

**OPSOMMING**

Die stygende vraag na vis as gevolg van bevolkingsgroei, tesame met die stagnering van die aanbod van vis vanaf natuurlike vangste het daartoe aanleiding gegee dat die oë van die wêreld op akwakultuur gerig is om die gaping in die voorsiening van vis te vul. Akwakultuur het ontwikkel as die enigste volhoubare manier om aan die groeiende vraag na vis te voldoen. Die vinnige uitbreiding van akwakultuur het egter toenemende besorgdheid in die nadelige omgewingsimpak, veral ten opsigte van akwakultuurafval, tot gevolg gehad. Die nethokstelsel wat tans deur kleinskaalse forelboere in die Wes-Kaap in oop watergebaseerde sisteme gebruik word en die vrystelling van afval in die wateromgewings wat onafwendbaar is, plaas 'n vraagteken oor die langtermyn volhoubaarheid van die nethokstelsel forelboerdery in besproeiingsdamme in die Wes-Kaap.

Die studie het ten doel gehad om geïdentifiseerde produksiestelsels wat deur akwakultuurboere gebruik kan word om die akkummulasie van organiese afval in besproeiingsdamme te verminder, te vergelyk. Die voorgestelde "skoon" produksietegnieke sluit in nethokke wat aan 'n opligstelsel gekoppel word, 'n semi-intensiewe drywende tenk- stelsel ("SIFTS system" in Engels) en 'n geïntegreerde akwakultuurstelsel. Met hierdie studie is bevind dat die geïntegreerde stelsel die mees effektiewe manier is om afval te herwin en toon potensiaal om akwakultuur op 'n vohoubare pad te plaas aangesien dit aan die volhoubaarheidsdimensies van geen emissie, voedingstofherwinning en geïntegreerde produksie voldoen. Meganiese metodes van afvalherwinning soos die nethok-opligstelsel en die SIFTS-stelsel is effektief in die herwinning van vastestofdeeltjies, maar opgeloste voedingstowwe word steeds in die omgewing vrygestel.

Die studie het voorts ten doel gehad om te bepaal of die ekonomiese, omgewings- en sosiale voordele om afval uit besproeiingsdamme te herwin, groter is as die herwinningskoste van die verskillende produksietegnieke. Modelle van kleinskaalse akwakultuurplase wat die drie geïdentifiseerde produksiestelsels gebruik, is ontwikkel en aangewend om te vergelyk met 'n nethokstelsel waar geen afvalherwinning gedoen word nie. 'n Vergelykende finansiële ontleding van die gemodelleerde kleinskaalse forelboerderye met die verskillende produksietegnieke is gedoen en daar is bevind dat enige een van die drie "skoon" stelsels finansieel lewensvatbaar is, met die SIFTS-stelsel wat die hoogste vergoeding aan die boer bied, gevolg deur die geïntegreerde stelsel, dan die nethokke aan 'n opligstelsel en dan die nethokstelsel sonder afvalherwinning.

Die tweede deel van die studie het van die voorwaardelike ("contingent") waardasiemetode gebruik gemaak om die omgewings- en sosiale voordele om afval uit besproeiingsdamme te verwyder, te

bepaal. Huishoudings het aangetoon dat hulle bereid sou wees om tot R40 per jaar te betaal om die waterkwaliteit te verbeter vanaf ’n toestand waar eutrifikasie plaasgevind het na ’n toestand waar die water vir besproeiing en akwakultuur geskik sou wees. Om die waterkwaliteit vanaf ’n toestand geskik vir besproeiing te verander na ’n toestand geskik om in te swem, sou huishoudings bereid wees om R16.67 per jaar te betaal. Indien water vanaf ’n toestand geskik vir besproeiing verander sou word na ’n toestand geskik vir huishoudelike gebruik, sou huishoudings gewillig wees om jaarliks R26.17 te betaal. Die “gewilligheid om te betaal” dui aan dat daar bo en behalwe die finansiële voordele om van “skoon” produksietegnieke gebruik te maak, ook omgewings- en sosiale voordele vir die plaasgemeenskap bestaan met die gebruik van die water uit die besproeiingsdamme.

## ACKNOWLEDGEMENTS

I am grateful to all who provided assistance to make this research possible and successful.

Thanks are due to Dr. JP Lombard my supervisor, your guidance, careful instructions and time exerted towards completion of my program is greatly appreciated. I would also like to express my thanks and gratitude to Prof. TE Kleynhans, Prof. N Vink, Prof. ASM Karaan and Mr W Hoffman. I also thank Prof. DG Nel for assisting in statistical analysis, special mention also goes to Mr K Salie, Mr G Steyn and Ms K Holmes of the Division of Aquaculture of Stellenbosch University and Hands-On Fish Farmers Cooperative for allowing me to carryout research involving their members.

Special thanks also goes to the non-academic staff at the Department of Agricultural Economics, namely Mrs T Bergstedt and Mr B Meyer for the technical support throughout the duration of my study. To my brother Dr. T Tasara and sister Mrs RF Kaseke, thank you for your financial and moral support. All my friends and family thank you. The following words by Winston Churchill kept me going "Never, never, give up".

Most of all, to our Lord Almighty, who daily provides strength and wonderful grace, your word is a constant source of inspiration to make things possible.

**TABLE OF CONTENTS**

## LIST OF TABLES

**LIST OF FIGURES**

**LIST OF ANNEXURES**

## LIST OF ACRONYMS

**BCR:** Benefit Cost Ratio

**CVM:** Contingent Valuation Method

**DWAF:** Department of Water Affairs and Forestry

**FAO:** Food Agriculture Organisation

**FCR:** Food Conversion Rate

**IFPRI:** International Food Policy Research Institute

**IRR:** Internal Rate of Return

**NPV:** Net Present Value

**SIFTS:** Semi-Intensive Floating Tank System.

**SOFIA:** City of Bulgaria where fish demand and supply estimates were made during the Fish summit held in 2005

**WTA:** Willingness to Accept

**WTP:** Willingness to Pay.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the study

Aquaculture is defined as the "propagation, improvement, or rearing of aquatic organisms (animals) in controlled or selected aquatic environments (fresh, sea or brackish waters) for any commercial, subsistence, recreational or other public or private purposes" (Heinrichsen, 2007). It is an old practice that is believed to have originated and practised in Asia for centuries in rural farming communities where it significantly contributed to aquatic food supply to households. The practise have spread through to most countries over the years and aquaculture is now a well established industry that contributes significantly to the global fish output. In recent years, the total global harvest of fish from natural sources has remained constant and this has resulted in the world turning to aquaculture for fish supply (FAO, 2007). The world population is expected to increase from the current 6 billion to 9 billion by 2050 and focus has shifted to aquaculture as it is the only sustainable option available to supply the growing population with fish and other aquatic organisms. With the current scenario of global emphasis on sustainable development, aquaculture presents an alternative form of fish production and supply to human kind that will help in reducing pressure on over exploitation of natural fish stocks.

The successful growth of global aquaculture industry in many instances has been matched by growing concerns for the negative impacts that aquaculture poses on water resources. Although the industry is growing, considerations should be made that water resources are limited and efforts must be made to sustain or improve the quality of water resources that are available. The growth in aquaculture has led to an increase in the use of feeds applied to water for improved production and this has resulted in more waste being added to the environment from aquaculture farms in form of uneaten feed and fish excretes (Miller & Semmens, 2002). Environmentalists, consumers and members of the general public are increasingly demanding aquaculture to account for its resource use as well as to balance its proposed benefits with its environmental sustainability (Muir et al., 1999). The environmental and resource use conflicts raised suggest that the present form of aquaculture development is not sustainable hence the need for environmental planning based on principles of sustainability (Ghosh, 2000).

In South Africa, aquaculture development has also been on the increase particularly in the Western Cape. One of the freshwater species that has been identified and targeted for fresh water production in the Western Cape is rainbow trout (Maleri, 2007). In 2007, South Africa was a net importer of the species and the processing industry relied on imports for the majority of its requirements

(Maleri, 2007). The tourism industry also relies on imports of the species for stocking recreational fisheries. Production of rainbow trout has been increasing over the past decade and rainbow trout is now the largest produced fresh water aquaculture species by volume in South Africa with an estimated 1 600 tonnes produced in 2005 (Botes et al., 2006). Rainbow trout production in South Africa is restricted by high ambient temperatures that prevail throughout the country and lack of suitable water. Rainbow trout can be successfully cultured in temperatures below $18^0$C and this restricts production of trout to higher regions of Western Cape, Eastern Cape, and Mpumalanga as well as around the foot of the Drakensburg and midlands areas of Kwa-Zulu Natal (Shipton & Britz, 2007). The network of dams and climatic conditions in the Western Cape makes it suitable for production of rainbow trout in irrigation dams and storage reservoirs using net cage systems (Du Plessis, 2007).

The successful completion of small scale net cage trout production systems trials in irrigation dams in 1995 opened a new chapter in small scale rainbow trout farming in the Western Cape. The results of the investigations indicated the feasibility of rearing rainbow trout in net cages in irrigation dams. In order to support historically disadavantaged members of the community and supply the processing industry with trout, a cooperative that was named Hands-On Fish Farmers Cooperative was formed in 2002 (Maleri, 2007). The aim of forming the cooperative was to coordinate and facilitate issues such as marketing, bulk buying, juvenile fish supply, financing, training, promotion and growth (Division of Aquaculture, 2005). The establishment of small scale rainbow trout farms in irrigation dams in the Western Cape provides an opportunity of supply of relatively cheap high quality protein, employment and income to rural communities.

The number of small scale rainbow trout farms in irrigation dams that are operating under Hands-On Fish Farmers Cooperative has been increasing around the Western Cape. Small scale rainbow trout farmers use net cage production system to grow rainbow trout from fingerlings to a size acceptable on the market during winter months. A net cage system is a production technique of raising fish in frames enclosed on all sides by net screens that hold fish inside allowing for water exchange and waste removal into the surrounding water. While the conservation of natural resources and social issues related to intergrated resource use of irrigation dams has been addressed by the existing production technique, issues pertaining to technological soundness and environmental sustainability need to be further investigated for intergration of small scale trout farming into the planning process.

The establishment of small scale net cage systems in private dams is based on agreements between the farmer and the workers on promise of good management practice as well as maintenance of good water quality in the dams. The net cage production technique used by small scale rainbow trout farmers is an open system where waste produced from the aquaculture farm is added into the dam water. Waste added from aquaculture farms comprise of uneaten feed, dead fish and fish excretes. The addition of waste into the dam water raises concerns over the impacts of aquaculture on water quality in irrigation dams. In order for small scale rainbow trout farmers to maintain good water quality in dams, there is need for them to use strategies that minimise waste coming from the aquaculture farm. Aquaculture farmers should also consider adopting production techniques that recovers waste to ensure that they honour the agreement that they enter into with the owner of the farm. This study investigates the strategies and alternative production techniques that can be used by the small scale trout farmers to minimise environmental impacts of their activities on the dam. 'Clean' aquaculture production techniques will ensure that small scale aquaculture farming expand in an environmentally friendly manner without jeopardising water quality in irrigation dams.

## 1.2 Rationale of carrying out this study

Although South Africa is a relatively dry country, it has a good infrastructure for water storage that can be used for multiple purposes. Aquaculture presents farmers with an opportunity to maximise benefits on water resources that are available. Introduction of small scale aquaculture in irrigation dams has helped in improving the health status of farm communities through direct consumption of high quality fish protein and indirectly through income that is used to purchase other forms of high quality protein. Collected data from previous research by Du Plessis (2007) on dams in the Western Cape gave a good indication of impacts of aquaculture on water quality, biological and economic sustainability. An investigation into production techniques available to farmers will help improve long term sustainability of small scale rainbow trout farming in irrigation dams. Sustainable production techniques will help small scale rainbow trout farmers meet part of the agreement they enter with the farm owner on maintaining good water quality in irrigation dams.

In order to ensure prolonged life of small scale rainbow trout farming on irrigation dams, there is a need to investigate methods and production techniques that are available that can be used by these farmers to reduce environmental impacts. Identification of the production techniques and assessment of their effectiveness will give farmers options when they are faced with the environmental problems related to net cage aquaculture farming. Due to the different cost outlays of production technique alternatives, the analysis will help farmers choose the production technique that will give them the best returns while reducing the environmental impacts of aquaculture. The results of the study will also help in future development of small scale trout farming in irrigation dams through use of the identified production techniques.

## 1.3 Problem statement

The net cage production technique used by small scale rainbow trout farmers in the Western Cape is an open system and release of waste and nutrients from the system is inevitable. Direct environmental impacts of the aquaculture farms mostly come from the release of organic nutrients as solid waste (uneaten feed and feaces) and dissolved nutrients (nitrogen and phosphorus). A net cage embedded in a dam generates a significant amount of solid wastes and if the waste is allowed to break up and become dissolved in the water, it becomes increasingly difficult to remove them. Waste coming from the small scale aquaculture farm has a potential of causing changes in water quality that might end up affecting the primary use of water from the dam that is the irrigation of fruit trees and vegetables. Previous research by Maleri (2007) indicated that problems related to water quality have emerged in more than half of the small scale rainbow trout farms in the Western Cape.

Due to the observed effects of aquaculture farms on the environment, the management of aquaculture waste has become a topic of intense regulatory scrutiny as more stringent waste management regulations are being developed for the entire industry. Increasing competition for water use and the responsibility of government agencies to predict and regulate environmental impacts is resulting in more restrictions on water use and effluent emissions. Reduction of waste from aquaculture is now a matter of growing concern as production of farmed fish continues to rise (Davenport et al., 2003). In order for small scale aquaculture to survive in a regulatory environment where there are tight effluent control measures, there is a need for aquaculture farmers to reduce environmental impacts. There is a great need for farmers to adopt production techniques that minimise pollution and optimise the recovery, disposal and re-use of solid wastes. This study identifies strategies and production techniques that can be used by the small scale trout farmers to minimise waste accumulation in irrigation dams. The main challenge faced by the small scale farmer will be to choose the most effective production technique in removing waste. The study generates information that will help farmers make a choice of the production technique that gives the farmer the highest returns and reduces environmental impacts of aquaculture.

## 1.4 Research question

The central research question addressed by this study was to identify suitable, effective and viable production techniques that can be used by small scale rainbow trout aquaculture farmers to ensure long term sustainability of aquaculture in irrigation dams. The question is whether the identified production techniques are biologically acceptable, economically viable, environmentally sustainable and socially acceptable.

### 1.5 Subproblems

1. Describe the structure of aquaculture farming in the Western Cape.
2. Determine the legal structure that surrounds environmental pollution control and water use in farming areas in the study area.
3. Identify and describe alternative production techniques that can be used by aquaculture farmers to reduce environmental impacts of aquaculture.
4. Assess the suitability, transferability and cost-effectiveness of application of the identified production techniques to small scale rainbow trout farming in irrigation dams.
5. Compare the costs of production and economic viability of the alternative production techniques.
6. Evaluate the social, economic and environmental costs and benefits that arise from removing organic waste using the production techniques.

### 1.6 The hypotheses

1. There is an established aquaculture farming systems that comprise of large scale commercial fish producers and small scale fish producers in the Western Cape.
2. There are legal structures that govern environmental pollution in water bodies that have to be adhered to in aquaculture.
3. There are various cost effective alternative production techniques that can be transferred and used by small scale rainbow trout farmers to minimise environmental impacts of aquaculture on irrigation dams.
4. Production technique that results in the least amount of nutrients and solids loading into the dam is the most effective.
5. Benefits of the different production techniques outweigh costs.
6. The social, economic and environmental benefits of removing organic waste coming from aquaculture farms in dams outweigh costs of putting in place the production techniques.

### 1.7 Methods used

Research was done by means of web searches, e-mails, and farm visits, personal interviews using a questionnaire and meetings with people involved in aquaculture. An extensive review of literature on impacts of cage aquaculture systems on the environment was carried out. Strategies and alternative production techniques that can be used by small scale rainbow trout farmers to minimise environmental impacts of aquaculture were identified from literature. Secondary data on production activities of small scale rainbow trout farms in the Western Cape was obtained from the Hands-On Fish Farmers Cooperative. Based on production techniques identified from literature and data obtained from Hands-On Fish Farmers Cooperative, two questionnaires were designed. The first questionnaire was used to collect information from small scale rainbow trout farmers. Visits to all small scale rainbow trout farms in the Western Cape could not be done due to various constraints but in order to give a representative overview of the topic at hand, interviews were conducted across the Western Cape (Worcester, Botrivier, Wolsely, Franschoek, Paarl and Stellenbosch). The small scale rainbow trout farm questionnaire was mainly used to collect information on production, investment costs for small scale rainbow trout farms and strategies that farmers are using to minimise waste accumulation. Information on rainbow trout prices and fingerlings costs was collected from Three Streams Smokehouse, a company that supplies fingerlings and buy fish from the farmers.

Data collected was used to develop a model of a typical small scale rainbow trout farm in the Western Cape. Since some of the production techniques are new designs, examples of farms where the techniques are in use to minimise impacts of aquaculture were identified from literature. Additional information was collected from contacts in countries where there are in use. Production information of the techniques was obtained and local costs were estimated. Theoretical models of typical small scale rainbow trout farms using identified production techniques were developed and adapted for South African conditions. After developing models of the farms, discussions were arranged with experts involved in local aquaculture and changes were made based on their input. Mass balance models were then used to assess nutrient loading on farms that use the alternative production techniques to determine the most effective method. A comparative financial analysis of the production techniques was then carried out to determine the financial viability of fish production using the techniques.

A second questionnaire was developed to collect information from households on the same farms where the small scale farm questionnaire was filled in. The questionnaire was used to collect information on willingness to pay (WTP) for techniques that can be used to improve water quality in irrigation dams. The data collected was analysed using STATISTICA and willingness to pay for water quality improvements was estimated.

## 1.8 Layout of thesis

This thesis consists of seven chapters. In Chapter 1, a background to the study is given followed by a summary of why and how the study was conducted. Chapter 2 gives a description of the global and South African aquaculture industries. The focus of this chapter is on identifying trends that aquaculture development will take in future and the regulatory framework of aquaculture in South Africa. In Chapter 3, literature is reviewed starting with the concept of sustainability and its application in aquaculture development. The effects of aquaculture on water quality are also discussed and a review on strategies as well as techniques that can be used in aquaculture to reduce environmental impacts is presented. In Chapter 4, data collection strategies and methods used to analyse the data are described. Chapter 5 presents results of small scale rainbow trout farms survey and models of small scale farms using different production techniques alternatives. Chapter 6 presents results and discussions of household survey and lastly Chapter 7 presents conclusions and recommendations.

# CHAPTER 2

# DESCRIPTION OF AQUACULTURE INDUSTRY

## 2.1 Introduction

The development of aquaculture in different parts of the world occurred in different patterns under diverse socio-economic conditions. In general, the primary interest in aquaculture development was directed towards establishing a viable aquaculture industry for the purpose of domestic consumption, export, employment creation, income generation or a combination of these objectives. This chapter gives an overview of the global aquaculture industry and trends in development of the industry in South Africa. The second part of this chapter discuss the institutional and legislative framework for aquaculture development in the Western Cape so as to provide a background of where environmental concerns raised in the use of net cage production technique investigated in this study, come from.

## 2.2 Overview of the global aquaculture industry

The history of aquaculture can be traced back to Asia where it is believed to have started around 2000 BCE (Phillips & Silva, 2007). The global aquaculture industry has grown dramatically and matured into a major industry in the last half century. Global aquaculture output has grown at an average rate of 8.8 percent since 1970 as compared to 1.2 percent growth from natural capture fisheries. Aquaculture now contributes around 43 percent of the total world fish output (FAO, 2005; FAO, 2007). Rapid growth of the global aquaculture industry in the past 50 years was driven by supply and demand. The desire to diversify the economic base of farmers through optimum use of available water resources, quest for food security as well as huge investments in research and rapid transfer of technology to all corners of the globe also played an important part in development of aquaculture. Expectations and realisations that fish production from natural captures would eventually fail to meet demand of fish, which led to the development of fresh water and marine aquaculture. Fish production from the aquaculture industry is expected to rise in order to maintain fish supplies to the rising human population.

### 2.2.1 Global trends in aquaculture production

Global fish production has been increasing steadily since the 1950's. In 2004, global fish production had reached 140 million tonnes with aquaculture contributing 45.5 million tonnes (FAO, 2007). Inland aquaculture (fresh water and brackish water) contributed 27.2 million tonnes of fish and marine aquaculture 18.3 million tonnes. Aquaculture production is a dominant activity in developing nations and they contribute more than 80 percent of global aquaculture output.

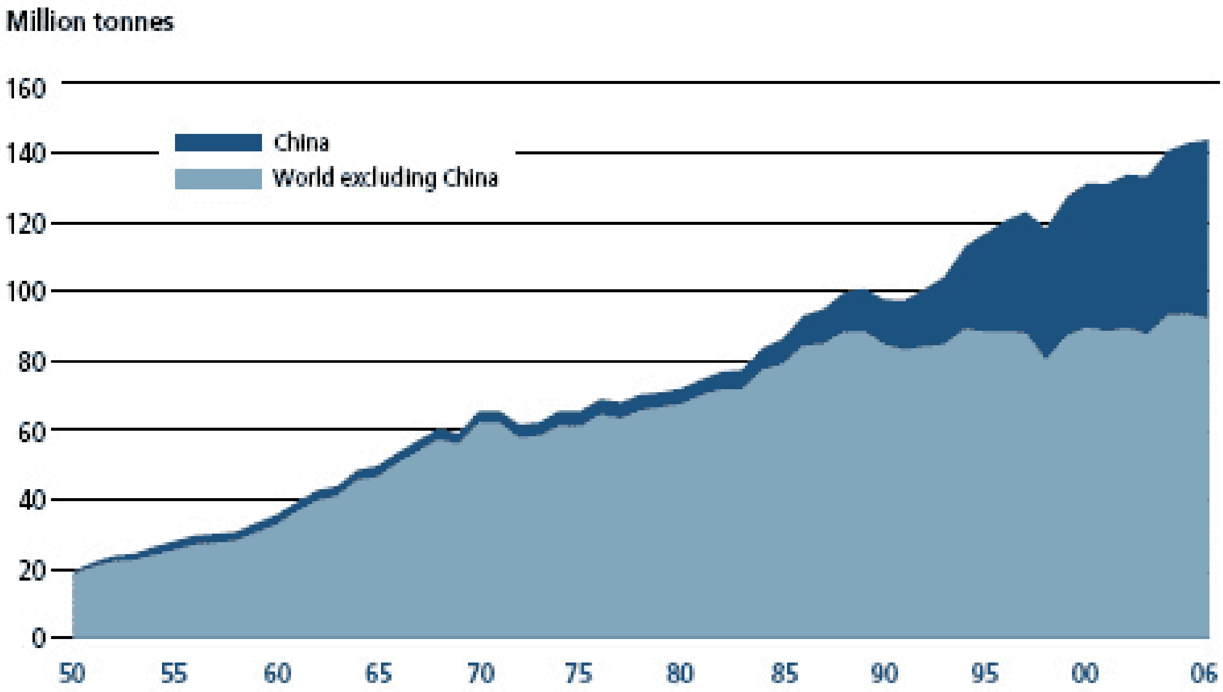



**Figure 2.1: World capture and aquaculture production trends from 1950-2006**

Source: FAO (2006a)

China is the largest fish producer from both natural capture and aquaculture, producing 47.5 million tonnes of fish in 2004 as compared to 77.9 million produced by the rest of the world (Figure 2.1). The most notable growth in aquaculture in the past occurred in China that currently contributes 70 percent of the global fish output from aquaculture (FAO, 2005). The Chinese revolution in aquaculture began over a thousand years ago. Successful intergration of aquaculture with agricultural activities in rural areas enabled farmers in China to optimise benefits from water resources. In China, farmers have managed to improve environmental sustainability of aquaculture farms through polyculture, intergrating a number of fish species in the same water to deal with waste produced from aquaculture. If long term sustainability of aquaculture is to be attained, lessons can be drawn from the path taken in development of the Chinese aquaculture industry.

### 2.2.2 Future trends in global aquaculture production

Table 2.1 shows projections of the expected changes that will occur in the fisheries and aquaculture production as estimated by various organisations. It is projected that fish output from inland and marine capture will stagnate around 93 million and aquaculture production will have to increase to meet the rising demand of fish due to population growth. The projections by FAO show that aquaculture development is of paramount importance in future, if quantities of fish supplied are to match quantities demanded

**Table 2.1**: **Fish production in 2004 and projections for 2010 and beyond**

| **Information source** | **FAO** | **FAO** | **SOFIA** | **FAO** | **SOFIA** | **IFPRI** | **SOFIA** |
|---|---|---|---|---|---|---|---|
| **Simulation target year** | **2000** | **2004** | **2010** | **2015** | **2020** | **2020** | **2030** |
| Marine capture (mil t) | 86.8 | 85.8 | 86 | n/a | 87 | n/a | 87 |
| Inland capture(mil t) | 8.8 | 9.2 | 6 | n/a | 6 | n/a | 6 |
| **Total Capture (mil t)** | **95.6** | **95** | **93** | **105** | **93** | **116** | **93** |
| ***Aquaculture(mil t)*** | ***35.5*** | ***45.5*** | ***53*** | ***74*** | ***70*** | ***54*** | ***83*** |
| Total production (mil t) | 131.1 | 140.5 | 146 | 179 | 163 | 170 | 176 |
| ***Percentage contribution from Aquaculture (%)*** | ***27%*** | ***32.4%*** | ***36.3%*** | ***41.3%*** | ***43%*** | ***31.8%*** | ***47.7%*** |

*Note:* mil t- million tonnes;   n/a- no figure was available;
SOFIA- projections made at SOFIA (capital city of Bulgaria) Fish summit in 2005
IFPRI- projections made by the International Food Policy Research Institute
FAO-projectionss made by Food Agriculture Organisation

Source: FAO (2006a)

Production from aquaculture needs to increase to 62 million tonnes per year by 2025, if it is to meet the level of consumption of 19 kg of aquatic products per person per year achieved in 1989 (Davenport et al, 2003).

**Table 2.2: Population growth projections by continent (millions)**

| **Population mid-year** | **Africa** | **Americas** | **Asia** | **Europe** | **Oceania** | **World** |
|---|---|---|---|---|---|---|
| 1950 | **227.3** | 338.9 | 1402.9 | 547.5 | 12.8 | **2529.3** |
| 2000 | **810.4** | 834.0 | 3 678.5 | 731.4 | 30.6 | **6 084.9** |
| 2010 | **1 016.5** | 937.0 | 4 149.3 | 728.8 | 35.3 | **6 866.9** |
| 2020 | **1 251.9** | 1 036.0 | 4 611.5 | 720.0 | 39.8 | **7 659.3** |
| 2030 | **1 507.9** | 1 126.2 | 4 992.7 | 702.4 | 43.9 | **8 373.1** |
| 2040 | **1 783.5** | 1 203.0 | 5 290.8 | 678.6 | 47.3 | **9 003.2** |
| 2050 | **2 073.0** | 1 263.7 | 5 503.3 | 648.9 | 50.1 | **9 539.0** |
| Growth (1) | **909%** | 381% | 383% | 119% | 401% | **373%** |
| Note: (1) - growth in percentage from 1950 until 2050 (i.e. 2050 population divided by 1950 population). | | | | | | |

Source: Geohive (2009)

Table 2.2 indicates expected population growth in different continents. Population growth is the most important factor that will determine future demand of fish hence trends in development of aquaculture. World population is expected to rise by over three billion to reach 9.5 billion people in 2050. If fish supplies from natural capture are to stagnate at 93 million tonnes as estimated by

SOFIA in Table 2.1, then output from aquaculture have to increase to 88.2 million tonnes (to maintain the level of 19 kg aquatic products per person per year) by 2050 to cater for the expected rise in demand due to population growth. Aquaculture production will be expected to double from the 45.5 million tonnes output attained in 2004 to 88.2 million tonnes in 2050 (FAO, 2006a). These figures indicate that aquaculture development will play an important role in filling the gap between quantities supplied and demanded.

Although there has been a rapid growth in global aquaculture production, Africa still lags behind and only contributes about two percent of global output despite its great potential (FAO, 2006a). The slow growth of aquaculture development in Africa was noted by stakeholders at the New Partnership for Agriculture Development (NEPAD), "Fish for All Summit" in 2005 (FAO, 2007). Despite the great potential of aquaculture in Sub-Saharan Africa, aquaculture contributes only 0.16 percent to global aquaculture output. The abundant water resources in Sub-Saharan Africa present a great opportunity for aquaculture development to meet future demand of fish. In 2005, the NEPAD "Fish for All Summit" raised international awareness about the potential of aquaculture in Africa, thus for the coming years and decades, aquaculture is likely to become a priority for development (FAO, 2006a). Indications are that assistance to Africa's aquaculture sector has been renewed in ways that are long term in nature and favour private investment. The great potential that the region possesses, if fully utilised, would result in an increase in production of aquatic products and supply of a significant amount to the world. It is in this regard that development of sustainable fresh water aquaculture is of increasing importance.

### 2.2.3 Trends in international trade

Trade in aquatic products have played an important role in development of the global aquaculture industry. It has been instrumental in stabilising quantities and prices of aquatic products around the world. Aquatic products can be produced in one part of the world and sold in other parts of the world. In many countries, the development of industrial/commercial aquaculture is as a result of opportunities presented by trading in aquaculture products. In 2004, total world trade in fish and fishery products reached US$72.2 billion, a huge increase from 1999 when only US$35.5 billion worth of aquatic products were traded (FAO, 2005). Increase in production from the aquaculture industry in developing countries has become an important source of fish products that has supplemented previously luxurious fish products at lower prices around the globe. The main traded aquaculture products are shrimps, prawns, salmon, molluscs, tilapia, sea bass and sea breams (FAO, 2006b).

## 2.3 Overview of the South African aquaculture industry

Commercial aquaculture production in South Africa began contributing meaningfully to the country's fish output in 1984 with a small catch of less than 100 tonnes (FAO, 2004). Production grew steadily peaking in 1991 for the pre-1994 era. The pre-1994 era had restricted growth of aquaculture in South Africa because of market and technological isolation that resulted in aquaculture production being restricted to the supply of local markets only (Salie & Van Stade, 2004). Improved access to international markets and technology adoption resulted in a shift in focus of aquaculture from the small and medium enterprises that characterised the pre-1994 era to the emergence of an industrial aquaculture sector that produces for export markets. Although aquaculture production has increased in South Africa, the industry is still a long way from realising its full potential.

### 2.3.1 Aquaculture farming structure and production in South Africa

Aquaculture in South Africa can be categorised according to environment, production scale, farming systems and farming characteristics.

#### 2.3.1.1 Classfication of aquaculture according to environment

Classification according to environment divides the aquaculture sector in South Africa into fresh water aquaculture and marine aquaculture (mariculture). Marine aquaculture utilizes coastal waters while fresh water aquaculture utilizes inland water resources such as river systems, lakes, dams, reservoirs, ponds and catch basins. In a benchmarking survey of aquaculture, Botes et al. (2006) found that from the 64 aquaculture producers who responded to the survey, there were 43 fresh water aquaculture farms and 20 marine aquaculture farms in South Africa in 2004. 43.8 percent of the farms were located in the Western Cape.

#### 2.3.1.2 Classification of aquaculture according to production scale and techniques

Aquaculture farms in South Africa can be classified according to production intensity. Farms are categorised as intensive, semi-intensive and extensive depending on stocking density of fish fingerlings and amount of feed given to the fish. Development of aquaculture in South Africa has seen a shift from the traditional extensive methods of production to more intensive methods where fingerlings are mostly bought in from well established hatcheries. Closely associated to classification of aquaculture according to production techniques is the division of the South African aquaculture industry into large scale producers (with a turnover of more than R5 million per year) and small scale producers with a turnover of less than R5 million per year. Table 2.3 indicate that there were 15 large scale aquaculture farms in South Africa in 2006 with five of them fresh water farms and 10 marine based farms (Botes et al., 2006). The number of small scale fresh water aquaculture farms has been increasing over the years in the Western Cape. A number of small scale farmers operating under the Hands-On Fish Farmers Cooperative producing rainbow trout in irrigation dams have increased significantly over the years.

**Table 2.3: Classfication of aquaculture farms according to scale of production.**

| Nature of operation | Fresh water | | Marine water | | Total | | Percentage of total | |
|---|---|---|---|---|---|---|---|---|
| | 2006 | 2008 | 2006 | 2008 | 2006 | 2008 | 2006(n=64) | 2008(n=74) |
| Large Scale (>R5m turnover per year) | 5 | 5 | 10 | 14 | 15 | 19 | ***23.4*** | ***22.7*** |
| Small scale(<R5m turnover per year) | 30 | 39 | 7 | 14 | 37 | 55 | ***57.8*** | ***65.5*** |
| Community project | 2 | 2 | 0 | 0 | 2 | 2 | ***3.1*** | ***2.3*** |
| Enterprise not yet in production | 2 | n/a | 1 | n/a | 3 | n/a | ***4.7*** | ***n/a*** |
| Wholesaler of produce | 1 | n/a | 0 | n/a | 1 | n/a | ***1.6*** | ***n/a*** |
| Production for private use | 1 | n/a | 0 | n/a | 1 | n/a | ***1.6*** | ***n/a*** |
| Production for recreational purpose | 1 | n/a | 0 | n/a | 1 | n/a | ***1.6*** | ***n/a*** |
| Production for tourism industry | 1 | n/a | 1 | n/a | 2 | n/a | ***3.1*** | ***n/a*** |
| Other | 0 | 2 | 1 | 6 | 1 | 8 | ***1.6*** | ***9.5*** |
| **Total** | **43** | **48** | **20** | **34** | **63** | **84** | ***100*** | ***100*** |

*Note: n/a means data was not available*

Sources: Botes et al. (2006); Britz et al. (2009)

### 2.3.1.3 Classification of aquaculture according to farming systems and characteristics

Since 1994, aquaculture in South Africa has adopted new structures and production techniques as a way of meeting the demand for fish and creating benefits for the community. The aquaculture production techniques and systems currently used in South Africa intend to address some of the challenges fish farmers face, that include creation of an environment that profitably produces aquatic products of desired quality and quantity. The production techniques used in aquaculture vary according to the cultured species and the water source.

Basically, production techniques used in both aquaculture subsectors can be divided into two main groups i.e. the land based production techniques and the water based production techniques. With land based techniques, land is required to build water holding structures and water is diverted from the water body to the structure. Land based production techniques include ponds, recirculated tanks, trays in ponds, raceways, tanks and baskets. The most frequently used production techniques in South Africa within marine and fresh water subsectors are tanks (56.3%), recirculation tanks (32.8%) and raceways (Botes et al., 2006). On the other hand, water based techniques involve the production of fish in water bodies where fish are exposed to the natural conditions of the water environment. The commonly used water based techniques in both marine and fresh water subsectors are net cages, pens, long lines, baskets and floating tanks. From the 64 farmers interviewed in 2006, 10.9 percent of the farms used net cage production technique (Botes et al., 2006). The use of net cage production technique has increased especially in the Western Cape where the number of small scale net cage trout producers has increased from five in 2004 to 30 in 2009.

Both land and water based production techniques face similar environmental problems caused by accumulation of organic waste. However the problem of organic waste accumulation in land based techniques can be dealt with as there are several methods that have been developed to remove the waste. The main challenge has been to find methods of dealing with organic waste accumulation in water based production techniques like net cages and enclosures or pens. Although there a several methods that have been put forward to reduce accumulation of organic waste, there is little known about their effectiveness.

### 2.3.2 Cultured species in South Africa

The main cultured fresh water species in South Africa include rainbow trout, tilapia, common carp, Koi carp, cray fish, ornamental fish, shrimps, mullet, bass, larbeo, african catfish and waterhawthorne. While the main cultured marine species include oyster, seaweed, abalone and mussels. In marine aquaculture, production of abalone has rapidly increased in the last ten years. Restrictions on harvest of wild abalone have resulted in rapid expansion of abalone farming especially in the Hermanus area (FAO, 2004). In 2000, there were 15 commercial abalone farms that produced 500 tonnes of abalone fish with a value of R150 million of which 80 percent of the production came from the Western Cape (Karaan & Rossouw, 2004). In 2008, production of abalone increased to 934 tonnes with a value of R268.20 million (Britz et al., 2009). Restrictions on harvesting of abalone presented itself as both a challenge and an opportunity for fisherman. It resulted in an increase in the number of fish farms to keep the market supplied with abalone and save employment and incomes in the industry. Aquaculture production of abalone is set for growth due to the prevailing high prices on the international market that are driven by high demand and low quantities supplied. Other marine and fresh water species that show potential growth in aquaculture farming are trout, kelp, mussels, oysters and seaweed for both the domestic and international market as currently South Africa is a net importer of these species.

### 2.3.3 Human resources in aquaculture

Although the fish industry contributes less than one percent to GDP, it is of great importance especially in the Western Cape where the sector employs a large number of people and contributes significantly to the livelihoods of coastal communities. In 2003, an estimated 17 000 people were directly employed in the fish industry, and the secondary and associated industry employed 12 000 people (Karaan & Rossouw, 2004). However, aquaculture employs only 4.3 percent of the people working in the fish industry.

**Table 2.4: Distribution of workers according to skills in aquaculture.**

| Year | Professional (manager/owner) | Skilled | Middle service | Semiskilled | Unskilled | Total |
|---|---|---|---|---|---|---|
| 2001 | 53 | 30 | 44 | 88 | 242 | **457** |
| 2002 | 53 | 32 | 45 | 94 | 341 | **565** |
| 2003 | 65 | 42 | 52 | 129 | 437 | **725** |
| 2004 | 68 | 41 | 56 | 135 | 453 | **753** |
| 2005 | 69 | 49 | 52 | 145 | 482 | **810** |
| 2006 | 118 | 98 | 69 | 468 | 1100 | **1735** |
| 2007 | 126 | 108 | 69 | 464 | 1197 | **1838** |
| 2008 | 151 | 127 | 72 | 518 | 1225 | **1942** |

Sources: Botes et al. (2006); Britz et al. (2009)

In 2005, there were 64 surveyed marine and fresh water aquaculture farms that employed 810 workers from professional to unskilled labour (Table 2.4). Inland aquaculture employed 281 people while marine aquaculture employed 529. In 2008, the number of people employed in aquaculture had more than doubled with a total of 1 942 people employed (Britz et al., 2009). If aquaculture is to grow as projected by Shipton and Britz (2007), then 20 000 more jobs will be created in the aquaculture industry in the next 15 years. A significant number of people are employed in the fish processing industry and growth in aquaculture will result in more jobs created in the associated industries.

### 2.3.4 Aquaculture production trends in South Africa

In 2006, 3 907 tonnes (Table 2.5) of aquaculture products worth R211 million were produced in South Africa as compared to 500 000 tonnes worth R1.8 billion from natural capture fisheries (Shipton & Britz, 2007). In 2008, although aquaculture production fell to 3 568 tonnes in quantity, its value increased to R327 million (Britz et al., 2009). Although aquaculture contributes a small portion of the total fish output, the sector's contribution has grown over the years and a similar trend is expected in future. Shipton and Britz (2007) projected that aquaculture in South Africa is set to grow from the 3 907 tonnes produced in 2006 to over 90 000 tonnes in 15 years creating more than 20 000 jobs (Table 2.5).

**Table 2.5: Projected growth potential of the South African aquaculture sector over 10-15 year period in terms of production, jobs and value**

| Species | Production 2006 (tonnes) | Value 2006 (R million) | Jobs on farms 2006 | Production Projection *10–15 yrs Tonnes* | Value Projection *10-15 yrs ZAR million* | Jobs Projection *10-15 yrs On farm* |
|---|---|---|---|---|---|---|
| Abalone | 833 | 158.4 | 670 | 2 895 | 551 | 2171 |
| Marine finfish | 0 | 0 | 20 | 40 000 | 1 400 | 8 000 |
| Oysters | 202 | 8.08 | 40 | 1 000 | 40 | 200 |
| Mussels | 900 | 5.1 | 23 | 8 000 | 45 | 400 |
| Prawns | 0 | 0 | 40 | 15 000 | 35 | 4 000 |
| Scallops | 0 | 0 | 4 | 100 | 8.4 | 40 |
| Bait organisms | 0 | 0 | 0 | 20 | 4 | 10 |
| Seaweed | 664 | 0.996 | 13 | 3 000 | 4.5 | 50 |
| Catfish | 66 | 0.99 | 33 | 10 000 | 150 | 2 500 |
| Tilapia | 80 | 1.2 | 40 | 10 000 | 150 | 2 500 |
| Trout | 1 100 | 25 | 533 | 2 300 | 52 | 767 |
| Salmon | 0 | 0 | 0 | 600 | 21 | 12 |
| Ornamental Fish | 1.3 | 2.9 | 50 | 6.5 | 13.2 | 50 |
| Koi Carp | 11.2 | 7 | 300 | 112 | 19.7 | 3 000 |
| Carp (food) | 40 | 0.6 | 20 | 100 | 1.5 | 50 |
| Bass | 9 | 0.45 | 18 | 15 | 0.75 | 30 |
| **Totals** | **3 907** | **211** | **1 805** | **93 149** | **2 496** | **23 780** |

Note: Production data is for the aquaculture sector in 2006, not on the 64 surveyed farms by Botes et al., 2006.

Source: Shipton & Britz (2007)

The projections indicate that development of aquaculture in South Africa will be very important for employment creation. There has been a shift in aquaculture development with the sector showing a high degree of commercialisation and more large scale aquaculture farms were established in the Eastern and Western Cape. The prospects of future development of aquaculture in South Africa are bright as huge strides have been taken to overcome the constraints that have been hindering development of the industry.

South Africa is a net exporter of fish and export of aquaculture products is set to increase. Table 2.6 indicate that there has been significant growth in production of marine species such as abalone and mussels. Table 2.6 show that production from aquaculture has increased over the years in terms of quantities but in value terms it has fluctuated. The decrease in value terms can be attributed to fall in prices of certain species on the world markets as well as appreciation of the Rand in 2004, 2005 and in 2009. The growth in output can be attributed to improved trade relations that have resulted in increases in exports of abalone and mussels to international markets.

**Table 2.6: Aquaculture production data according to cultured species, 1998-2006**

| Year | 1998 | | 2000 | | 2003 | | 2006 | | 2008 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Species | Qty (t) | Value (R m) | Qty (t) | Value (R m) | Qty (t) | Value (R m ) | Qty(t) | Value (R m) | Qty(t) | Value (R m) |
| **Marine** | | | | | | | | | | |
| Abalone | 22 | 5.94 | 180 | 36 | 515 | 134 | 833 | 158.4 | 934 | 268.20 |
| Oysters | 175 | 14.25 | 170 | 5.1 | 250 | 1.6 | 202 | 8.0 | 289 | 8.47 |
| Mussels | 650 | 15.9 | 790 | 5.135 | 542 | 5.1 | 900 | 5.1 | 600 | 6.0 |
| Prawn | n/a | n/a | n/a | n/a | 130 | 11.8 | 0 | 0 | 4 | 0.15 |
| Finfish | n/a | n/a | n/a | n/a | 10 | 0.4 | 0 | 0 | n/a | n/a |
| **Fresh water** | | | | | | | | | | |
| Trout | 1650 | 24.750 | 1830 | 35.402 | 1300 | n/a | 1100 | 25 | 943 | 27.98 |
| Tilapia | 45 | 0.585 | 130 | 1.475 | 160 | n/a | 80 | 1.2 | 10 | 0.30 |
| African catfish | 40 | 0.48 | 65 | 0.667 | 50 | n/a | 66 | 0.99 | 180 | 3.60 |
| Common Carp | 45 | 0.54 | 55 | 0.585 | 30 | n/a | 40 | 0.6 | n/a | n/a |
| Mullet | 12 | 0.18 | 15 | 0.157 | 15 | n/a | 20 | 0.3 | n/a | n/a |
| Large mouth bass | 5 | 0.09 | 8 | 0.055 | 9 | n/a | 9 | 0.45 | n/a | n/a |
| Marron Cray fish | 4 | 0.3 | 2 | 0.331 | 8 | n/a | 30-40 | 5.5-7.4 | 0 | 0 |
| Koi carp | 128000 | 135 | 375000 | 4.1 | 77 | n/a | 11.2 | 7 | 514.2m fish | 1.80 |
| Aquarium | n/a | n/a | n/a | n/a | 30 | n/a | 2600 boxes | 2.86 | 608 | 0.67 |

Note; Qty – Quantity; Rm- million Rands

Sources Shipton & Britz (2007); Karaan & Rossouw (2004); Britz et al. (2009)

Abalone production increased by 61 percent from 515 tonnes in 2003 to 833 tonnes in 2006. In 2008, abalone production dominated the South African aquaculture production with a value of R268 million representing 81 percent of the total Rand value of the aquaculture sector (Britz et al., 2009). Twenty four percent of the total tonnage of abalone was exported bringing in 82 percent of the total value of South African aquaculture production. The period between 2006 and 2008 has also resulted in the introduction of farming of new species like the dusky kob, silver kob and yellow tail (Britz et al, 2009). There has also been a significant growth in production of fresh water species like trout and tilapia. Development of aquaculture in irrigation dams, notably in Mpumalanga and Western Cape, has contributed to the increase in the production of fresh water fish species (Botes et al., 2006).

## 2.4 Aquaculture in the Western Cape

The Western Cape is the centre of aquaculture farming in South Africa and the province is leading the way in development of the industry. Western Cape leads in aquaculture development because the fish industry has always been very important in the province as it employs a large number of people. Job losses associated with declines in landings from the marine capture fisheries amongst other factors motivated the establishment of aquaculture. If the experience and lessons learnt from development of marine and freshwater aquaculture in the Western Cape is to be transferred to other provinces, then South Africa is set to become a leading producer of aquatic products (Rouhan & Britz, 2004).

The huge strides taken by post apartheid government in training of aquaculturists and establishment of departments specializing in aquaculture at universities and institutes of technology cannot be overlooked in the development of aquaculture in the Western Cape (Rouhan & Britz, 2004). Investment in research and successful initiation and expansion of new species was very important in the establishment of aquaculture in the Western Cape. However, Rouhan and Britz (2004) in their "Baseline survey of the aquaculture industry in South Africa" noted that there is still a great potential of growth in aquaculture sector in South Africa. Lack of a clear policy in terms of aquaculture development affects the transformation of potential growth of aquaculture to actual growth. The various organisation and stakeholders involved in aquaculture came together and put together a policy document that outlines the development path that aquaculture is to take that now waits to be implemented. Increased participatory role and implementation of aquaculture national policy will go a long way in development of aquaculture in the country. The aquaculture sector in the Western Cape is also divided into marine aquaculture and fresh water aquaculture.

### 2.4.1 Marine aquaculture (mariculture) in the Western Cape

Marine aquaculture is the farming of aquatic organisms that include fish, molluscs, crustaceans and plants in controlled environments. Marine aquaculture is relevant to the Western Cape, as the province is well known for the harvest of natural marine resources, and also possesses the potential for the development of a strong marine aquaculture sector. In 2004, 2 650 tonnes of fish were produced from marine aquaculture and the subsector employed 529 people (DEAT, 2006). About 69 percent of marine aquaculture production take place in the Western Cape (ESS report (2003), cited in Karaan & Rossouw, 2004). In 2006, there were 20 marine aquaculture farms, 10 of them large scale with a turnover greater than R5 million (Table 2.3).

The decline in fish catches in South Africa's West Coastal areas resulted in closure of a number of fishing processing establishments resulting in numerous job losses and economic hardships (Karaan

& Rossouw, 2004). The large numbers of jobs lost in the West Coast led to the establishment of aquaculture farms along the coast line. Marine aquaculture presented an opportunity to increase diversification of economic activities in coastal areas and this subsector is set for huge growth as outlined in the marine aquaculture policy document that is set to be implemented. Marine aquaculture is very important as it involves production of high value species such as abalone, oyster, mussels and seaweeds. The production of abalone has recently made South Africa one of the main producers of the species as its production increased from less than 100 kg in 1996 to 833 tonnes in 2006 with an export value of R178.3 million (Shipton & Britz, 2007). The implementation of the marine aquaculture policy and the high profit margins associated with the marine aquaculture species will probably result in further expansion of the subsector.

### 2.4.2 Freshwater aquaculture in the Western Cape

Fresh water aquaculture in South Africa has a long history that stretch back to the time when small scale aquaculture were introduced in the former native home areas in the 1940's (Venda, Lebowa, Gazankulu and Transkei) (Rouhan & Britz, 2004). The main aim of introduction of fresh water aquaculture then was to improve food security in these areas without much development of the sector as a potential commercial industry. However the experience gained formed a good base to develop fresh water aquaculture in the Western Cape and to provide relatively cheaper source of protein in areas where there was scarcity of fish and high levels of poverty. Given the province's water resources, climate, biological potential and socio-political factors, the prospects of developing fresh water aquaculture in the Western Cape economy have always been important (Hoffman, 1990).

Currently South Africa has more than 3 000 private and state owned dams with a minimum capacity of 50 000 $m^3$ and depth of 5 metres that are suitable for fresh water aquaculture (DWAF, 2008). The Western Cape has more than 2 000 dams with a combined sustainable potential production capacity of 8 000 tonnes of fish per annum (Rouhan & Britz, 2004). The available fresh water resources are suitable for fresh water aquaculture and if they are fully utilised for aquaculture, South Africa can replace Egypt as the largest producer of aquatic organisms in Africa. However, growth in fresh water aquaculture in the Western Cape has been slow considering its potential. There are several constraints that are faced in development of aquaculture in the province. Rouhan and Britz (2004) noted that the slow growth in aquaculture could be attributed to the fact that aquaculture is actually a capital intensive activity which does not require a large amount of labour and suggested that a greater degree of commercialisation will be the most logical way in which aquaculture should develop in the future.

Shipton and Britz (2007) also noted that the main constraints that have been affecting fresh water aquaculture development in South Africa include access to water and land, access to technology, high transaction costs, and lack of supporting policy and legislation as well as barriers of entry to certain markets. Overcoming the above mentioned constraints are of paramount importance in development of aquaculture and there are many lessons that can be drawn from Australian and Chinese aquaculture sectors to adress these problems.

### 2.5 Institutional framework for aquaculture regulation in South Africa

The commitment made by the government to environmental sustainability is reflected in the South African Constitution (1996). The constitution which is the basis for policy and law making in the country contains clauses that have far reaching effects on attainment of environmental sustainability. The Bill of Rights contains a clause on environmental sustainability which provides that "… everyone has the right to an environment that is not harmful to their health or well-being" (South African Constitution, 1998). Part (b) of this clause gives government the responsibility to take reasonable measures to ensure that the environment is protected for the benefit of present and future generations, and gives government the responsibility to take "… reasonable legislative and other measures that prevent pollution and ecological degradation, promote conservation, and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development" (South African Constitution, 1996). The contents of the environmental clause have also been supported through implementation of key policies and frameworks governing socio-economic development and natural resource management.

The regulation of fresh water aquaculture and marine aquaculture in the previous cabinet fell under the Ministry of Environmental Affairs and Tourism (DWAF, 1996a). In the new cabinet announced in May 2009, functions of the Ministry of Environmental Affairs and Tourism were transferred to three new ministries namely Ministry of Tourism, Ministry of Water and Environmental Affairs and Ministry of Agriculture, Forestry and Fisheries. At provincial level, it is the responsibility of the departments and local governments to ensure that all water uses are sustainable and as such water use for aquaculture requires authorisation from the Department of Water and Environmental Affairs (DWEA) that approves in consultation with the Department of Agriculture Forestry and Fisheries and local municipalities. For land based aquaculture where water is to be abstracted from a water source and used somewhere in large quantities there is need for application for a water permit or license that seeks to ensure that water is allocated in a responsible and fair manner. For re-circulated systems where large volumes of water are to be extracted there is need to apply for such a permit and to a certain extent the applicants have to adhere to certain water discharge requirements as it is a legal requirement that water discharged back into a system should not exceed a certain level of pollutants or meet certain standards as set by the Directorate of Water Quality (DWAF, 1996a; Heinreichsen, 2007).

## 2.6 Legislative framework for aquaculture in South Africa

Environmental issues in aquaculture have always attracted the attention of many researchers in the field of aquaculture in many countries. In many countries, the discharge of nutrients and waste from aquaculture facilities is regulated through legal measures (Ackefors & Olburs, 1995). Karaan (2005) noted that regulation of aquaculture in South Africa is complex and the application process is complex hence the need to make regulation more user friendly, transparent and understandable. Karaan (2005) also noted that progressive regulation in aquaculture should be adequate to protect interests of the society and at the same time simple to promote investment in the industry. In South Africa, there are a number of laws that govern the development of aquaculture that will be discussed in this section.

### 2.6.1 National Water Act, No 36 of 1998

The National Water Act, No 36 of 1998 is the primary legislation that regulates use of water bodies for aquaculture. The Act gives the government the responsibility to ensure that water is fairly accessed and distributed and the mandate to ensure that water is used in a sustainable manner (DWAF, 1998). This Act is very important as aquaculture is dependent on use of the water resource. Although cage aquaculture is a non-consumptive water use, it is the environmental impacts of waste produced from the system that is of concern. The Act regulates pollution in water resources and requires aquaculture producers to adhere to certain limits on effluent discharge. Aquaculture producers are required to ensure that water remains fit for use for any beneficial purpose that it can be expected to be used and should not pose any health or safety risks to human beings, animals, and property and to any aquatic or non aquatic organisms.

Subsection 18 requires aquaculture producers to ensure that water resource remains of high quality after use so that it can be used by the next users without adversely affecting the activities of the next user (DWAF, 1998). In cases where water quality has decreased, aquaculture farmers are required to put in place clean up measures to improve the quality of water hence the need for aquaculture to adopt cleaner production techniques. In May 2009, the Department of Water Affairs published a legal notice that requires registration of waste discharge from water users as defined in terms of Section 21 of the National Water Act. Section 21(f&g), requires aquaculture producers to register as they are described in these sections as discharging waste into water sources and disposing waste in a manner which may have detrimental impact on a water resource (DWAF, 1998).

### 2.6.2 National Environmental Management Act, No 107 of 1998

The Act has provisions that aim to protect the environment and ensure that habitants of South Africa live in an environment that is not harmful to their health and well being. This is mentioned in Chapter 3, 7, 8 and 9 of the Act that strives to develop a framework for intergrating good environment management into all developmental acitivities (DEAT, 1998b). The law promotes justifiable economic and social development through prevention of pollution and ecological degradation, promote conservation, and secure ecologically sustainable development and use of natural resources. It also seeks to promote cooperative governance in implementation of environmental plans and management plans. The development of aquaculture has to pay particular attention to this Act especially the section on prevention of pollution and ecological degradation.

### 2.6.3 Animal Diseases Act, No 35 of 1984

The Act provides for the control of animal diseases and parasites especially for animals imported into South Africa. It sets out the procedure that should be followed on importation of animals so that the animals do not bring with them diseases that might cause outbreaks and losses to the local animals. Importing animals into South Africa requires permitting as outlined in Section 6 of the Act. In Section 7, animal importers are required to take precautionary measures in order to ensure that diseases are not imported with the animals. It is an important Act for the development of aquaculture as it prevents spread of diseases from imported aquatic organisms that might have adverse effect to the growing aquaculture industry.

### 2.6.4 Animal Improvement Act, No 62 of 1998

This Act complements the Animal Diseases Act as it provides for improvement of the production and performance of animals through breeding, identification and utilisation of genetically superior animals. Fish are classified as animals in the Animal Diseases Act and as such genetic improvement of fish or importation of genetically superior fish breeds is regulated through this Act. It is very important to the fish industry as it regulates the establishment of hatcheries that are very important for supply of fingerlings to fish producers. It is also important for development of intergrated polyculture systems as some of the species that can be successfully intergrated with trout are exotic species that need to be imported.

### 2.6.5 National Environmental Management: Biodiversity Act, No 10 of 2004, Alien and Invasive Species, Regulation 2008

The Act controls the unauthorised introduction of alien species and invasive species to ecosystems. It ensures that alien species and invasive species introduced in an ecosystem are properly managed and controlled to prevent and minimize their harm to the environment and to biodiversity (DEAT, 2004). It is an important act in development of aquaculture as it ensures ecological sustainability. Since demand and supply largely determines the future developments of aquaculture in terms of species to be farmed, there is need to ensure that introduction of alien exotic species is controlled and environmental impacts are well researched before the alien species are introduced. It also requires farmers to eradicate alien species and invasive species from ecosystems and habitats where they may harm such ecosystem and habitats in order to protect the native species. Rainbow trout species farmed by the small scale farmers is an exotic species hence farmers should ensure that they are no incidences of fish escaping from the net cages.

### 2.6.6 Marine Living Resources Act, No 18 of 1998

The act sets the basic framework for monitoring, control and surveillance including licensing requirements of fisheries and aquaculture developments in coastal areas (DEAT, 1998a). This law is enforced by the Ministry of Water and Environmental Affairs except for the administration, powers and functions pertaining to marine aquaculture as defined in Section 1 of the Act, which transfers powers to to the Ministry of Agriculture Forestry and Fisheries as set out in paragraph 1.8. Paragraph 1.8 sets the administrative powers of marine aquaculture to the Ministry of Agriculture Forestry and Fisheries as entrusted in Sections 12, 13, 18, 25, 26, 28 and 77 with respect to marine aquaculture as mentioned in Marine Living Resources Act in paragraphs 78, 79, 80, 81 and 83 of the Act. It requires that the prospective aquaculture farmers apply for a license before setting up a farm in marine waters. The farmers are required to undertake an environmental impact assessment before approval of the proposed projects. The proposed project undergoes public scrutiny where people opposed to establishment of such projects raise their concerns and this ensures that aquaculture farms incorporate environmental cleaning.

## 2.7 Guidelines controlling aquaculture development in Western Cape

There are several self regulatory guidelines that have been published to ensure sustainability in aquaculture that include best management practices guide lines, production manuals, standards guidelines, permitting and licensing. The guidelines are mainly published to promote co-management of the environment between the community and the government, for example "Guideline to Authorisation" by Heinreichsen (2007). Water quality guidelines provide information to water users in specific sectors on water quality standards that are to be maintained if aquatic ecosystems are not to be disturbed (DWAF, 1996a; DWAF 1996b; DWAF, 1996c; DWAF, 1996d). They also empower water users to effectively choose the processes that meet water quality requirements in order to safeguard fresh water ecosystems.

Although the guidelines are not legally binding, they are valuable sources of information for aquaculture farmers. They raise awareness through informing water users of the functions of aquatic ecosystems as pollutant sinks that have an assimilative capacity for certain waste through self purification. It emphasise the need to protect the systems as they provide an aesthetically pleasing environment, provides livelihood to communities and maintain biodiversity. The main highlight from the guideline that should ensure that aquaculture should be done sustainable is the fact that, while it is possible to store and treat water for domestic use to acceptable quality, it is not possible to treat poor quality water to the same degree for aquatic ecosystems hence the need to put in place mitigation measures.

### 2.7.1 Best management practises

Best management practices in aquaculture are those practices determined to be most efficient, practical and cost effective measures selected to guide aquaculture or to address the environmental problems faced in aquaculture. The best management practices provide practical guidelines for aquaculture to avoid causing pollution and give recommendations on practise that optimise the environmental management of aquaculture operation. In the Western Cape, there is a "Trout production manual" published by Salie et al. (2008). The guideline is important in helping farmers minimise environmental impacts of aquaculture. It outlines management activities that are supposed to be carried out by the farmer in order to minimise environmental effects in a cost effective and continually assessed way (Heinrechsen, 2007). If the management activities outlined are followed, small scale farmers can reduce environmental impacts and help them comply with the legislative requirements for resource protection and conservation. Extension services and regular training of small scale farmers will help aquaculture farmers understand better the guidelines and management practices that can effectively improve successful intergration of aquaculture in irrigation dams.

### 2.7.2 Aquaculture licensing

The right to use waters of the Republic of South Africa for aquaculture is obtained through application for a licence. Aquaculture licenses are issued by the licence board, located in the Department of Agriculture, Fishery and Forestry in collaboration with the Department of Water and Environmental Affairs (formely DWAF). Application for an aquaculture licence follows a prescribed procedure, one of the requirements of which is to ensure that the proposed aquaculture activity does not harm the environment. Planning of an aquaculture facility is done based on integrated management of economic and environmental interests with the other sectors concerned. The same licence gives the right to use state controlled water for aquaculture activities, taking into consideration the recommendations and consensus of local competent authorities in the proposed area. There are also several by laws instituted by local governments that require to be observed and followed when planning for an aquaculture facility. An Environmental Impact Assessment is required as part of the licence application procedure for large scale aquaculture operation an aspect that is very important in ensuring sustainable development of aquaculture.

## 2.8 Summary

Aquaculture development is of great importance in ensuring adequate supply of fish products to the rapidly increasing populations. Increase in trade of fish products enables fish products to be produced in one region and supplied to other parts of the globe. Increased access to markets will drive future developments of aquaculture in South Africa because the country has suitable waters for production of high valued species. South Africa has an established marine and fresh water aquaculture industry that is expanding fast. The industry comprise of large scale and small scale farmers, with large scale farms mainly dominating in marine aquaculture and small scale farming prevalent in fresh water aquaculture. Small scale trout production in irrigation dams is a very important activity in the Western Cape and its development has been prioritised to supply trout for the processing industry. The industry employs a significant number of people and its development will be very important in employment creation. From the regulatory side, issues of environmental sustainability are well covered, but the question will always lie with the aquaculture farmers on whether they have the capacity to meet all of the requirements since aquaculture is still an emerging industry. Production techniques that minimises environmental impacts will be very important in expansion of small scale trout farming in irrigation dams as well as public dams that are used for multiple purposes.

# CHAPTER 3

# LITERATURE REVIEW

## 3.1 Introduction

This chapter begins with explaining the concept of sustainable development and its application to aquaculture. The chapter further discusses the potential effects of waste released from aquaculture on water quality in dams as well as how water quality changes affects use of water from the dam for multiple purposes. A review of literature on models that can be used to calculate nutrient loading in aquaculture systems is presented. Mitigation measures and alternative production techniques that can be used by aquaculture farmers to minimise the environmental impacts of aquaculture are also discussed in this chapter. The last part of the chapter reviews literature on methods that can be used in valuation of water quality.

## 3.2 Sustainable development of aquaculture

"Sustainable development" has been defined and interpreted in many ways by different authors. A definition that appears to be more acceptable and mostly used as the reference point is the one put forward by the United Nations in 1987, where sustainable development was defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (The Brundtland Report, 1987). This definition touched on the most basic components of the concept that use of resources in the present day should always take into consideration future generations. It led to a common understanding of the challenge that the world is facing and rethinking of the development path to be taken in order to move towards sustainability.

Aquaculture development like any agricultural activity should always take into account conservation of natural resources, technological improvement to reduce waste generation and waste removal, economic viability and social acceptance. The most common definition of sustainability that is applicable to aquaculture is the one put forward by Pillay (2004). It is referred to as the management and conservation of natural resources through orientation of technological and institutional change to ensure the attainment and continued satisfaction of human needs for the present and future generations (Pillay, 2004; Ghosh, 2000). It implies that the development plan that is chosen in aquaculture should be technically appropriate, economically viable and socially acceptable.

In the past, research and experimentation in aquaculture was guided by the objective of obtaining higher yields through intensifying aquaculture practices (Pillay, 2004). Focus on development of aquaculture was based on the principle of short term economic viability with very little attention on environmental sustainability. When aquaculture systems began showing a negative feedback with outbreak of diseases as a result of self pollution, there is a general recognition that environmental sustainability is a valid constraint in development of aquaculture which must be considered. Planning for aquaculture farms should be based on the concept of capacity to produce as well as capacity to absorb and assimilate waste.

The concept of sustainability has always been an important factor in development of aquaculture in the Western Cape as noted by Oberholster (2005) in his study of investigating the long term sustainability of aquaculture systems in the province. He noted that development of sustainable aquaculture in the Western Cape should always provide security, make a positive contribution towards the protection of production potential of natural resources, must be socially acceptable and maintain a high level of biological and economical productivity over the long run.

The development of small scale aquaculture in the Western Cape over the years has shown a high degree of sustainability as it meets the social and economic requirements of sustainability. However, there are concerns on its long term sustainability due to environmental concerns that are usually associated with the use of net cage production technique. There is need to improve the production technique so as to reduce the negative environmental risks that it poses in irrigation dams. Smyth and Dumanski (cited in Oberholster, 2005) outlined five important requirements for sustainable development of aquaculture and these are:

1. Maintaining or improving production levels (biological productivity).
2. Reducing risk and uncertainty through the timely identification and proper management of the various kinds of risk.
3. Protecting the production potential of natural resources (nature conservation).
4. Economic viability.
5. Socially acceptable.

It is important for farmers to use the five requirements as a check list of whether their farms are moving towards sustainability. The main problem faced by a net cage aquaculture farmer is water pollution caused by waste coming from the net cage system. However, Halwell (2008) noted that pollutants are merely ‘misplaced resources’ and their removal would drive aquaculture towards environmental sustainability. In order to reduce pollutants coming from net cage systems, farmers need to invest in production techniques that are aimed at improving the systems and reduce accumulation of organic waste.

### 3.3 Environmental sustainability principles in aquaculture

The ecological aspect of sustainable development is based on the concept of 'carrying capacity' referring to the maximum impact that a given ecosystem can sustain (Ghosh, 2000). Farmers should ensure that sites selected for aquaculture have the capacity to absorb waste released from the farm. Intensity of aquaculture farming operations determines the quantity of waste added into the environment from the farm. Assimilative capacity of waste depends much on the flushing rate of the receiving water body or the regular removal of waste for their disposal. The current design of net cage systems requires improvement so that waste can be removed quickly from water bodies. Removal of organic waste improves fish production and also ensures that water remains fit for use for multiple purposes hence movement towards environmental sustainability (Pillay, 2004).

In order to achieve environmental sustainability in aquaculture, the approach to the problem should be similar to approaches that have been used in dealing with environmental problems in the agriculture industry. The four fundamental environmental sustainability principles that are important in moving towards sustainability in aquaculture are: precautionary principle, prevention principle, polluter pays principle and proximity principle (Hartwick & Oleiweiler, 1998). The precautionary principle involves management of unknown risk where expectations are high that there will be negative effects from current actions hence the need to take measures to try and reduce the potential negative effects. In aquaculture, farmers are required to put in place measures that will ensure that aquaculture operations do not affect the environment. The prevention principle in aquaculture involves introduction of laws that regulates generation and treatment of waste produced from aquaculture farms. In application of this principle, action is taken before there are any signs of negative environmental impacts caused by aquaculture farms.

Polluter pays principle requires that aquaculture farmers incorporate negative externalities that might be arising from aquaculture into their production functions. In application of the polluter pays principle, the government put in place a regulatory framework that ensures that aquaculture farmers incorporate clean up costs in their production function. The future of aquaculture regulation in South Africa is more likely to be dominated by such regulations. Effluent regulations force aquaculture farmers to internalize the total environmental costs into their operations based on this principle. Aquaculture farmers in this regard should strive to internalize the environmental costs before regulation in form of penalties forces them to do so.

Recently, the government made amendments to the National Water Act (Section 21) requiring all aquaculture farmers to register and agree to discharge consents that will ensure co-management and control of pollution. With the introduction of discharge consents, aquaculture farmers agree to reduce waste discharged from aquaculture farms to acceptable levels and failure to meet the standards attracts a fine. Future development of aquaculture requires farmers to adopt ‘clean’ production techniques so as to avoid penalties that will be imposed. The government can impose taxes to be paid by polluters. Tax collected can then either be used to clean up pollution or compensate society for the damage caused by the pollution. In the second instance, the farmer pays for the cost of abatement of pollution so that no pollution is imposed on society. This underlies the polluter pays principle as it affects personal costs and benefits. It induces behaviour change from individuals or firms to more socially desirable alternatives (FAO, 2006b).

In applying the proximity principle the government puts in place a regulatory framework that requires aquaculture farmers to treat waste discharge from aquaculture systems especially before water is discharged back into the natural water system. An approach similar to that applied in industries and agriculture in treatment of waste is very important in ensuring that waste from aquaculture is treated before being discharged back into rivers or dams.

### 3.4 Ecosystem approach in aquaculture

The ecosystem approach (EAA) was defined by FAO (2006b) as “an approach to aquaculture that strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties of biotic, abiotic and human components of ecosystems including their interactions, flows and processes and applying an integrated approach to aquaculture within ecologically and operationally meaningful boundaries”. The main aim of the EAA is to plan, develop and manage the aquaculture industry in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by aquatic ecosystems.

The framework for implementation of EAA to attain sustainability in aquaculture can be done at farm level, geographical level and industrial level with norms and regulations that are relevant for each level. At farm level, the ecosystem approach (EAA) requires that sound environmental impact assessment or similar decision making tools that ensure proper consideration of and accounting of ecosystem effects of the proposed activities for new aquaculture facilities and development of retropespective impact assessments and mitigation tools for activities that already exist. Emphasis should be put on site selection, production level, species to be used, farming systems, production techniques and socio-economic effects at farm level.

On geographical scale, EAA can be implemented at biogeographical levels e.g. coastal, watershed and offshore marine where there are aquaculture activities (FAO, 2006b). Licence requirements for aquaculture farms as well as management guidelines and tools are important in sustainable development of aquaculture. Zoning is also an important concept in implementation of the ecosystem approach at geographical level. Issues such as genetic contamination from escapees, disease transmission, competition for land and water use are relevant at this level. At industry level, the EAA covers issues such as availability of raw materials for feed manufacture and broader ecosystem impacts on aquaculture and agriculture resources needs to be considered. Tools such as Life Cycle Analysis (LCA) of aquaculture feeds should be considered as most environmental concerns in aquaculture comes from nutrients added into the aquaculture systems through feed. There has been significant progress made in feed manufacturing industry as the trout feeds used by aquaculture farmers are high nutrient density feeds that are stable in water and contains low concentrations of nitrogen and phosphorus.

### 3.5 Environmental risks and impacts of net cage aquaculture

There are growing concerns on declining water quality in fresh water ecosystems in South Africa with very few rivers retaining their original function or ecological integrity (Nel et al., 2004 cited in DWAF, 2008). The pollution and degradation of water resources creates many problems such as increases in water temperature, sediment loads and turbidity levels (DWAF, 2008). This have adverse impacts on aquatic life, recreational value of inland water and increases the costs of treating water for domestic use. Water pollution is caused by both point and non point sources and measures should be put in place to reduce the pollutants that find their way into the water bodies. Although pollution from aquaculture is in small quantities as compared to other sources, it will always be important to minimise pollution at all levels no matter how small the quantities released into water bodies. Accumulation of organic waste in dams used for aquaculture continues to raise concerns even though the pollutants released are in small quantities. Aquaculture farmers should strive to produce a product that is not only acceptable to consumers in terms of price, quality and safety but also in terms of environmental costs. Volpe (cited in Halwell, 2008) noted that the main reason why fish is inexpensive is because costs are transferred to the environment and the society at large. The environmental aspect of aquaculture is important as a hedge against future regulations (Halwell, 2008).

Farm dams are artificial structures that are constructed to accumulate and store run-off water in order to meet agriculture demands such as irrigation, livestock watering, human consumption and aquaculture (Du Plessis, 2007). The dams have low current velocities and a high potential for organic sedimentation (Weston et al., 1996). The rate at which they can assimilate waste is always expected to be different from natural water bodies. Continous accumulation of waste from aquaculture brings into question long term sustainability of small scale net cage farming in dams and the use of dam water for multi-purposes. Farmers need to come up with strategies to minimize environmental impacts of aquaculture but in order to achieve this, it is important to know the nature and amount of waste produced from the net cage aquaculture farms.

### 3.5.1 Accumulation of organic waste in dams

A net cage system is a slight modification of a natural system with the only improvement being confinement of fish to a certain area and provision of feed to ensure fast growth of the fish. Concerns of net cage aquaculture are that the interaction between a farm and its environment could result in harmful feedback of the environment and the farm itself (Islam, 2005; Phillips et. al, 1985). Addition of external nutrients and energy in water bodies and in some cases, disruption or loss of community and social benefits is always of concern in net cage fish farming. Of the different aquaculture production techniques, intensive net cage aquaculture has the greatest potential to generate waste (Ghosh, 2000). Since a net cage is an open system, production of high volumes of waste and their release is inevitable (Beveridge, 1996). Waste falling off from the net cages is primarily composed of uneaten feed, partially digested feed, faecal matter, algae, and bacteria from the gut of the animal and other materials that the fish ingests (Blackely & Hrusa, 1989). The accumulated wastes decompose and cause oxygen depletion or generation of methane and other toxic gases under anaerobic conditions (Pillay, 2004). Net cages also increase deposition of silt at the bottom of the farm site (Davenport et al., 2003). As waste input increase at the bottom of the dam, the surface sediments become anoxic and only a small number of organisms can survive these conditions (Blackley & Hrusa, 1989). If benthic organisms are reduced by severe sedimentary anoxia, then decomposition of organic waste occurs at a very slow rate hence accumulation of waste at the bottom of the dam (Davenport et al., 2003).

Dissolved nitrogen and phosphorus is also added into the dam and these nutrients have a potential of enriching freshwater systems and cause eutrophication (Stigerbrandt, 1999; Guo & Li, 2003). According to Nhan et al. (2008), in study of integrated fish production systems where pig excrete was used to feed fish in ponds and the water used for irrigating fruit trees and rice in Vietnam, found that in the long run cage system would become unsustainable as more pig excreta continued to accumulate in the system. They found that around nine percent of input nitrogen will be recovered in harvested fish while the rest accumulate in the ponds. Guo and Li (2003), Davenport et al. (2003) and Bergheim (2007) reported that between 70 and 80 percent of nitrogen added in aquaculture farms is lost into the environment and 50 to 60 percent of total nitrogen is lost in dissolved form. The quantities of nutrients released from net cage systems contribute significantly to nitrogen and phosphorus that is dissolved in water. Phosphorus is the principal factor produced by the fish farms that has an effect on the freshwater system (Beveridge, 1984; Guo & Li, 2003). The amounts of phosphorus added into the environment from aquaculture activities should be of great concern to the aquaculture farmer.

### 3.5.2 Models that show organic waste accumulation in irrigation dams

In order to determine the extent to which organic waste accumulation in dams affects water quality as well as the society in general, it is important to establish relationships that exist between effluents from aquaculture, water quality and water use. The three relationships that are important in linking changes in the emission of pollutants from aquaculture to the ultimate measurement of the benefits of reducing the emissions are:

1. Technical model that link the nutrient budgets of feed added into the net cage systems to change in water quality due to effluent loading in the dam. The model predicts the path of the effluents from the aquaculture farm to the water around the cage.
2. Establish how the change in water quality affects the use of water from the dam by individuals. These include biological effects such as the impact on human health, effects on the economic productivity of the water resource and recreational uses of the ecosystem.
3. The change in environmental services and the change in economic welfare, or the benefits of abatement.

## 3.6 Technical models that link emission to pollution

There are two methods that can be used to estimate waste material lost to the environment i.e. direct methods involving sampling and analysis of the water column and sediment particulate matter and secondly indirect method using mass balance models (Ghosh, 2000; Islam, 2005). Direct methods can be used in semi-closed or closed systems hence not applicable to net cage systems. In this study indirect methods were used to quantify waste accumulation in rainbow trout farms that use different production techniques. In order to establish the effects of aquaculture on water quality, it was necessary to review the indirect method models that link nutrient or feed input into the system and the waste discharged from the system. In 1968, Vollenweider developed a mass balance model that was later modified and adapted for fresh water aquaculture systems by Beveridge (1984) and Islam (2005). The mass balance model is based on movement of nitrogen and phosphorus compounds through freshwater systems. Such models are useful in environmental impact assessment of aquaculture farms and management. Information on nutrient loading and forms of nutrients added into the environment enables appropriate measures to be devised for the sustainable development of aquaculture in irrigation dams.

### 3.6.1 Liao and Mayo model

Lia and Mayo (cited in Burynuik et al, 2006) established a relationship between feeding rates and suspended solids in trout production. They presented the relationship between feeding rates and suspended solids as:

***Suspended Solids (SS) = (0.52) F***

Where

SS- suspended solid production (kg SS/100kg fish/day)

F- Feeding rate (kg of food/100kg fish/day)

Source: Burynuik (2006)

The equation expresses waste as a fraction of feed applied. It shows that 52 percent of the feed added into a fish farm is lost as waste. Islam (2005) also mentioned the two factors that determine amount of waste produced as the amount of feed supplied and digestibility. This model only allows for calculation of suspended solids and does not calculate the amount of nutrients that are added as dissolved nutrients that have the greatest potential to cause negative environmental impacts on the dam system.

### 3.6.2 Modelling-On growing fish farms-Monitoring

The "Modelling-On growing fish farms-Monitoring" model designed by Stigebrandt (1999) is a viable tool that can be used by aquaculture farmers to maintain satisfactory environmental conditions in and around fish farms that is important for site selection (Ghosh, 2000). The model is directed towards adjustments of the local environment impact of fish farming, specific to the conditions of culture practices and holding capacity of sites. In the "Modelling-On growing fish farms-Monitoring" model (MOM), faecal matter per fish per day is expressed as a fraction of the maximum food ration per fish (g/day) or appetite (APP) as follows:

$$FL_{dw}=FL\ (APP)$$

Where

$FL_{dw}$-Faecal matter produced by fish per day

FL (unassimilated feed fraction) = $(1-A_p)E_p+(1-A_l)E_l+(1-A_c)E_c$

Where

App- maximum appetite

($A_p$- assimilated fraction of protein, $A_l$ lipid, $A_c$ carbohydrate, $E_p$ fraction of food supply by proteins, $E_l$ lipid, and Ec carbohydrate).

Croomey et al. (2000) also developed a simplified version of MOM called the deposition model (DEPOMOD) that estimates the amount of nutrients lost into the environment. Bergheim and Brinker (2003) showed the relationship between suspended dry matter loadings and feed conversion ratios. However the models only show solid waste that is generated from the fish on an aquaculture farm and does not indicate dissolved nutrients that come from the aquaculture farms that have potential to cause eutrophication of fresh water systems.

### 3.6.3 Nutrient budget and loading model

Islam (2005) developed a model that shows the relationship between nutrient input in net cage systems and nutrient loading in net cage systems as presented in Figure 3.1. Food conversion rate (FCR) refers to the amount of feed required to produce a kilogram of fish.

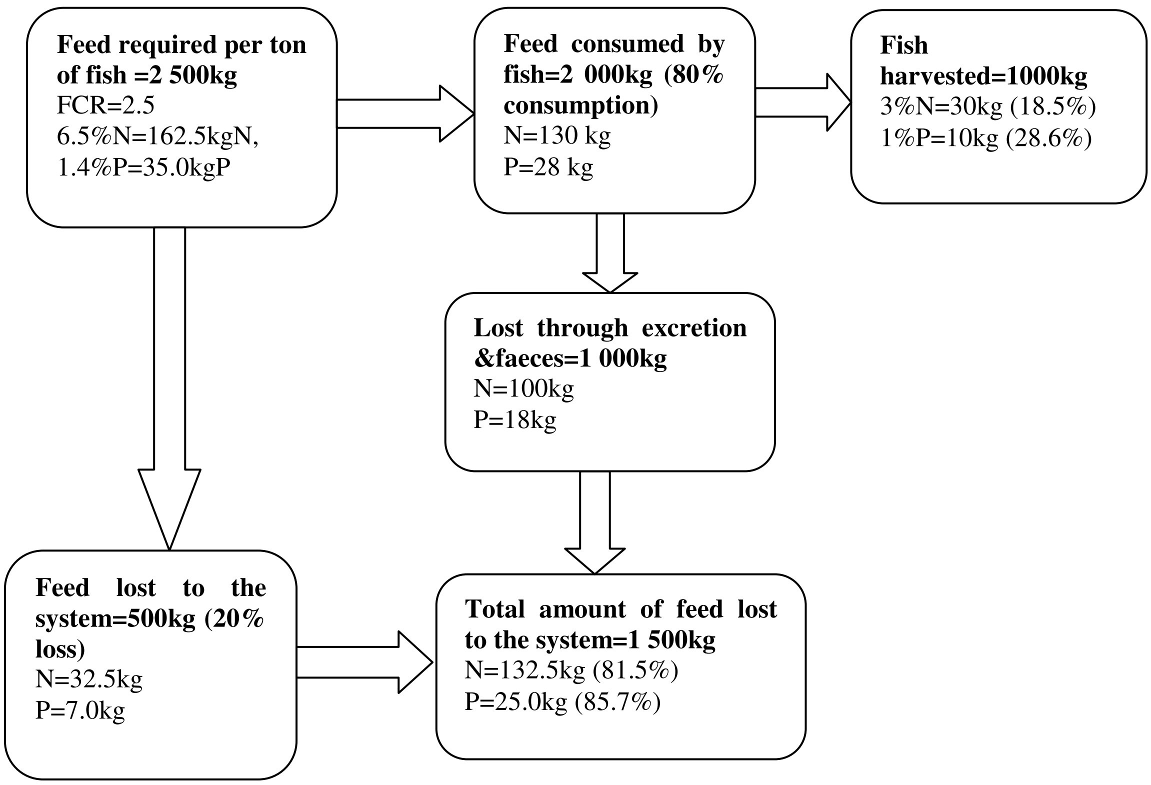



**Figure 3.1: Nutrient budget and loading model**

Source: Islam (2005)

The model in Figure 3.1 shows nutrient mass budget for a hypothesized net cage aquaculture farm. It shows the amount of feed that is added into a net cage system to produce a tonne of fish and the amount of nutrients released into the water body as uneaten feed and waste that accumulates at the bottom of the dam. The model shows that 81.5 percent of nitrogen added into the system is lost into the environment and 85.7 percent of phosphorus added as feed is also lost into the environment. It also indicates that 60 percent of the feed added into the system accumulates beneath the net cage as uneaten feed and fish waste. The model calculates that 132.5 kg of nitrogen and 25 kg of phosphorus is lost into the environment. However a number of studies reported lower amounts of nitrogen and waste added into the environment (Hall et al, 1992; Warren-Hansen, 1982a; Sumari, 1982, all cited in Islam 2005).

### 3.6.4 Mass balance model

Initially developed by Vollenweider (1968) and modified and adapted to aquaculture by Beveridge (1984) is the mass balance model presented in Environment Australia (2001). The model is a mathematical presentation of the nutrient budget model in Section 3.6.3 where the total nitrogen and phosphorus added into the environment from aquaculture farm is calculated as:

$$\mathbf{T_{N+P} = (F_{N+P} * FCR) - (A_{N+P})}$$

Where

$T_{N+P}$ is Total nitrogen and phosphorus added into the system (kg/t/fish)

$F_{N+P}$ is Total nitrogen and phosphorus in feed (kg/t)

FCR is Food Conversion Rate

$A_{N+P}$ is Nitrogen and phosphorus converted to fish biomass (kg/t)

Foy and Rosell (1991) and Ghosh (2000) also used a similar equation to determine nutrient loadings based on FCR value and the nutrient contents in the feed and in the fish as:

**Nutrient LOSS RATE= (FCR*FEED)–Fish**

Where

LOSS RATE-nutrient loss rate in kg/ton of fish produced

FEED-nutrient content of the diet in kg/ton

Accurate modelling of feed added into the system and waste falling out of the system is important in determining the most effective methods that can be used to minimise or recover waste that falls through the net cage system. Models are also important in determining the potential impacts of aquaculture activities on water quality and its suitability for other purposes. In this study a mathematical presentation of mass balance model was used to estimate the amount of nutrients added into dams from modelled small scale rainbow trout farms in the Western Cape.

## 3.7 Effects of changes on water quality to the flow of environmental services

To determine the extent to which waste from aquaculture affects use of water from the dams for multiple purposes, it is necessary to review the available information on minimum water quality standards that have to be maintained in dams. The term "water quality" refers to the suitability of water to sustain its different uses. DWAF (1996c), defined water quality as the physical, chemical, biological and aesthetic properties of water which determines its fitness for use and its ability to maintain the health of aquatic organisms. Water as a solvent has the ability to dissolve certain elements and remain fit for use up to a certain level and in water management it is important to always ensure that certain elements are maintained below certain levels or standards that do not affect aquatic organisms. The ability of water to perform its functions depends on the levels of constituents dissolved or suspended in it. If constituents are above a certain level they alter the ability of water to perform its function hence they are regarded as pollutants.

In South Africa, there are four broad categories of water use that are: domestic, industrial, agricultural and recreational (DWAF, 1996a). Use of water bodies for net cage systems is a non-consumptive use of water but release of nutrients into the water bodies can affect the fitness of water to be used for other purposes. In a dam being used for aquaculture, it is important to maintain water quality suitable for the above mentioned uses and above all aquatic ecosystems.

### 3.7.1 Toxic nutrients released from aquaculture systems

There are several nutrients that are released from aquaculture farms into the dam and are likely to affect suitability of water quality for various puposes. Water quality parameters that are important in assessing environmental impacts of aquaculture in irrigation dams are mainly dissolved oxygen, pH, carbon dioxide, ammonia, nitrites, nitrates, phosphorus, hydrogen sulphide and turbidity. Ammonia is a colorless odorless substance which can accumulate in water as a result of aquaculture activities. It causes fish mortalities, decrease in production and increased incidences of diseases in aquaculture (Pillay, 2004; Davenport et al., 2003). Although ammonia is produced naturally in the dam nitrogen cycle through the biological degradation of nitrogenous matter, the form in which it is present in water is always of concern in dams that contain aquaculture systems. Toxicity of water is directly related to the levels of unionized form ($NH_3$) as it contributes to eutrophication (Blackley & Hrusa, 1989). Organic waste that accumulates beneath net cage systems usually contributes to the levels of ammonia in the dam hence the need to control accumulation of organic waste.

Availability of dissolved oxygen in water is the most important factor that affects fish production. Maintenance of adequate oxygen concentration is critical for survival of aquatic organisms especially fish that are kept in the net cages. Under normal circumstances, oxygen is available in high concentrations as it is generated during photosynthesis. Fish rely on the amount of dissolved oxygen in water to support their metabolism while water's ability to take oxygen into solution depends on temperature, pressure and dissolved salts (Pillay & Kutty, 2005). This indicates that unless care is taken to ensure that there is adequate water exchange, fish will succumb to the effects of their own metabolism on water quality in terms of reduced oxygen, increased carbon dioxide, increased unionized ammonia and suspended solids.

Increased demand for dissolved oxygen for decomposition of organic waste causes shortages of oxygen and results in further decomposition of organic waste occuring anaerobically, producing toxic compounds such as hydrogen sulphide and methane (Sheperd & Brommage, 1988). Prugnin and Hypher (1981) noted that these substances affect productivity of the dam and reduces fish yields. An increase in organic waste is associated with blooms of blue green algae that can cause fish death in fresh water lakes (Prugnin & Hyper, 1981; Sheperd & Brommage, 1988, Blakely & Hrusa, 1989).

Phosphorus is the primary element that causes eutrophication in fresh water bodies (Pillay & Kutty, 2005; Pillay, 2004). An increase in concentration of phosphorus and nitrogen in the water will result in blooms of both green algae and blue green algae (Pillay, 2004). Algal blooms can consume all oxygen available during nocturnal respiration or by increasing the biological oxygen demand (BOD) if the bloom suddenly dies, which results in suffocation of fish stock (Pillay, 2004). Algal blooms also reduce the amount of light penetration in the water column. Blue green algae produce some compounds that give water an earthy/musty odour and taste that gives fish an off flavour taste (Pillay & Kutty, 2005). High pH values affects availability of trace elements in water and also affects the levels of unionized ammonia found in the water at any given time. A combination of high pH, low oxygen concentration and high temperatures results in high concentration of unionized ammonia that negatively affects fish growth.

Nutrient loading in water bodies results in excessive growth of phytoplankton or aquatic plants such as algae (DWAF, 1996c). Algae are always present in water bodies but only become of concern when blooms occur due to high concentrations of nutrients such as phosphates and nitrogen (DWAF, 1996d). There have been reported cases of fish kills caused by toxins secreted by blue green algae (Halwell, 2008). An algal bloom usually causes a reduction in dissolved oxygen levels in the water, where fish have to compete with algae for oxygen particularly at night. Although there are no known direct effects of algal blooms on fish, algal blooms reduces the amount of dissolved oxygen, which is harmful to fish (Blackely & Hrusa, 1989).

### 3.7.2 Effects of water quality on aquaculture

Management of water quality is the single most important factor in productive fish farming that helps a farmer to optimise production (Blakely & Hrusa, 1989). There are several physical and chemical parameters that should be maintained within a certain range if water is to be deemed fit for use for aquaculture. Blackley and Hrusa (1989) cited two sets of factors that affect the growth rate of individual fish in aquaculture and these are:

1. Factors that are related to the fish itself, such as genetic characteristics and physiological state (state of health, sexual maturity, etc.).

2. Factors related to the environment that is: chemical composition of water, water temperature, and metabolite level (the products of excretion), available oxygen and available food.

Metabolites level and available food contribute to accumulation of organic waste and as long as these two factors and oxygen do not limit growth, the fish attains their maximum growth potential for a given set of conditions of chemical composition of water and temperature (Blakely & Hrusa, 1989). Accumulation of waste from aquaculture farms contributes significant amounts of dissolved nutrients that can have adverse effects on the dam ecosystems. Hence the concentrations of nitrogen, oxygen, and phosphorus should always be monitored in dams that contain net cage aquaculture systems. Table 3.1 show the potential effects of constituents produced from fish farms on fish production.

From Table 3.1, it can be noted that it is important to keep the level of constituents such as ammonia, dissolved oxygen and pH within the target range so that there will be optimal fish production. Concentration of ammonia in dams used for aquaculture should be maintained in a range between 0.0 to 0.025mg for fish to attain optimal growth as shown in Table 3.1. Ammonia concentration of above 0.3mg causes adverse effects to fish production and aquaculture farmers should regularly carryout water analysis to ensure that ammonia concentration level do not surpass the critical level.

**Table 3.1: Criteria and health effects of specific nutrients on fish**

| Constituent | Concentration (mg in water) | Effect on fish |
|---|---|---|
| **Ammonia (mg $NH_3$ in water)** | 0.0-0.025 (target water quality requirement) | Ideal target for optimal fish production |
| | 0.025-0.3mg | Some sub-lethal effects, especially reduced growth rate of cold water fish. Blue sac disease in yolk sac fry of rainbow trout |
| | 0.3-1.10mg | Adverse physiological and histopathological (affects liver & kidney of fish) effects may occur |
| | 55mg | Chronic, reduced growth and increased feed conversion |
| **Dissolved Oxygen** | 0-2 mg in water | Lethal to rainbow trout |
| | 2.13-2.25mg | Minimum dissolved oxygen for brown and rainbow trout at 18$^{o}$C and 25$^{o}$C respectively |
| | 4mg | Respiratory stress in rainbow trout |
| | 5-6mg | Critical, dissolved oxygen for incubating and hatching of trout eggs |
| | 6-9mg (target water quality range) | Optimal growth and no stress at temperatures between 14$^{o}$C and 18$^{o}$C |
| | 16-21mg | Maximum safe concentration between temperatures at 25$^{o}$C for brown trout and 12$^{o}$C for rainbow trout |
| **pH** | Target Water Quality Range 6.5 - 9.0 | Most fish species will tolerate and reproduce successfully within this pH range and production is optimal. |
| | 3.0 - 3.5 | Lower tolerance limit of *Cyprinus carpio* (acute exposure). |
| | < 4.0 | Lethal to most salmonids: histological damage to gills, precipitation of gill mucus, blood circulatory failure. |
| | 4.0 - 4.5 | Lethal to rainbow trout if exposure continuous. |
| | 9.0 | Upper tolerance level for most species |
| | 9.5 - 10 | Upper tolerance level of rainbow trout |

Sources: DWAF (1996d); Pillay (2004)

The amount of dissolved oxygen in water is very important in fish production as oxygen is required by fish for metabolism. Dissolved oxygen in water is also used by aquatic plants at night during respiration and it is also used by aerobic bacteria during natural breakdown of waste. The level of dissolved oxygen is supposed to be maintained above 2.13mg (see Table 3.1) so that fish won't succumb to death due to shortage of oxygen. Table 3.1 also shows that pH should be maintained between 6.5 and 9.0 for optimal growth of fish. A pH of lower than 4.5 is lethal to trout production.

Aquaculture farms can be regarded as self regulatory because the effects of pollution are first felt on the aquaculture farm before other water users notice. If a fish farm produces more waste that cannot be taken care of by natural processes, fish on the farm feel the effects first and the farmer has to take necessary measures.

### 3.7.3 Effects of water quality on irrigation

Irrigation water is water used to supply the water requirements of plants which is not provided for by rain and refers to all the uses that water may be put to in the environment. In South Africa, irrigation agriculture is the largest consumer of available waters hence the need to keep most water bodies fit for this use (DWAF, 1996c). Irrigation water users may experience negative impacts as a result of changes of water quality and these include reduced crop yields, impaired crop quality, impairment of soil suitability and damage to irrigation equipment.

Nitrogen is one of the most important macro-nutrients required by plants. Inorganic nitrogen is available in different forms in water and these include ammonia, ammonium, nitrate and nitrite (DWAF, 1996c). The form that can be absorbed by plants from the soil is nitrate that is the more stable compound and the form in which nitrogen is available in water depends on the water temperature and pH (DWAF, 1996c). The availability of nitrogen in irrigation water determines the amount of fertilisers to be added. Nitrogen has a stimulatory effect on growth of plants when applied in excess of plant requirements as it causes excessive vegetative growth and lodging, delayed crop maturity and poor quality. Its potential to leach and contaminate groundwater as well as its stimulatory effects on aquatic plants in irrigation structures such as canals, storage tanks and dams is of concerns as it hinders the efficient distribution of irrigation water. Nitrogen is one of the elements added into water from aquaculture farms and the amounts added from aquaculture should be of concern in irrigation dams. Nitrogen causes rapid growth of aquatic plants in irrigation structures thereby reducing the carrying capacity of the irrigation structures and clogging of sprinklers (DWAF, 1996c).

Under natural conditions, the concentration of nitrogen in water is usually less than 0.5mg (DWAF, 1996c). Higher levels of nitrogen can have negative effects on sensitive crops and if nitrogen is applied in large quantities to pastures used as livestock feed, it can be hazardous to animals (DWAF, 1996a). Crops that are sensitive to nitrogen concentrations such as grapes may be affected when total nitrogen concentrations in irrigation water exceed 5mg. Most other crops remain relatively unaffected until nitrogen exceeds 30mg (DWAF, 1996c). These concentrations of either nitrates or ammonium are equivalent to nitrogen applications of 50 and 300 kg/ha respectively for an irrigation application of 1 000 mm. The pH of water plays a very important role in plant nutrition as the pH level affects the form or availability of certain elements in water. Application of irrigation water also has a potential of affecting soil pH hence absorption of micro-nutrients by plants. The pH levels have an effect on irrigation equipment as too acidic water has corrosive effect on irrigation equipment.

Suspended solids are insoluble sediments carried by water and arise from excessive erosion, destruction of riparian vegetation, construction activities, overgrazing and industrial, domestic waste and aquaculture. Suspended solids have no toxic effect on plants or soil but their effects are of physical nature (DWAF, 1996c). Small particles that are found suspended in irrigation water affects emitters used in drip irrigation and causes clogging of sprinklers in irrigation systems (DWAF, 1996c). This leads to a decrease in uniformity of water application and subsequent yield decreases. The abrasive action of particles leads to accelerated wear of sprinkler nozzles (decreased uniformity of water application) and other components (pumps, seals and control valves) of the distribution system. If suspended solids are present in high concentrations and are deposited on the soil surface they can lead to the formation of a surface crust which inhibits water infiltration, seedling emergence and reduces soil aeration. In sandy soils, suspended solids may have a beneficial effect as they improve the soil texture, constituency and water holding capacity. Deposition of suspended solids from aquaculture on plant leaves may reduce plant photosynthetic activity, result in reduced yields and affect the appearance as well as marketability of produce.

### 3.7.4 Effect of water quality on livestock

Although dams used for aquaculture should not be accessible to livestock, sometimes water is pumped from the dams to water tanks for livestock. It is important to maintain water quality to levels suitable for animals. Table 3.2 show chemical and biological parameters that can be tolerated by animals. Table 3.2 also shows that keeping lower levels of nitrogen from aquaculture farms is important in reducing effects of nutrients produced from aquaculture on farm animals. Concentration of nitrates and nitrites in dam water can be altered as a result of the amount of organic waste produced from aquaculture that will be naturally degraded by aerobic and anaerobic bacteria in the nitrogen cycle. Growth of potentially harmful toxic algae as a result of nutrient loading from natural degradation of organic waste from aquaculture is also of concern.

**Table 3.2: Water quality: Constituents that are potentially harzadous to livestock that can be added by effluent loading from aquaculture farms.**

| **Constituent** | **Concentration range (mg in water)** | **Effects** |
|---|---|---|
| **Nitrate($NO_2^-$) and Nitrite($NO_3^{2-}$) concentration of nitrites toxic to animals** | 0-100 (target water quality range) | No adverse effect to animals |
| | 100-200mg | Adverse effects in both ruminant and monogastric animals |
| | >200mg | Adverse effects to animals with effects such as restlessness, frequent urination, dyspnoea |
| **Toxic algae** | Cyanobacteria (freshwater blue green algae) Target Water Quality Range<br>• No visible blue-green scum<br>• < 6 colonies of blue-green algae/0.5 mR b<br>• < 2000 Microcystis cells/mR c | No adverse effects |
| | • No visible blue-green scum<br>• > 6 colonies of blue-green algae/0.5 mRb increased<br>• > 2 000 Microcystis cells/mRc | Low risk of acute toxic effects |
| | • Visible blue-green scum<br>• 6 colonies of blue-green algae/0.5<br>• > 2 000 Microcystis cells/mRc | • High risk of acute toxic effects<br>• Do not allow livestock to drink from mRb or have contact with the scum |
| **pH** | pH<5 | Clogging and chemical corrosion of livestock watering systems. |

Source: DWAF (1996b)

### 3.7.5 Effect of water quality on domestic uses

Water from dams is sometimes used for domestic purposes such as drinking, food and beverage preparation, bathing, personal hygiene, washing laundry and gardening. If water from dams used for aquaculture is to be used for domestic purposes, it is suppose to meet certain criteria. Poor water quality is likely to have negative health impacts to the users, aesthetic impacts due to changes in water taste, colour and odour, staining of household laundry and some economic impacts like increased cost of treatment and corrosion of water pipes (DWAF, 1996a). Table 3.3 summarises the effect of different concentrations of nutrients and other water constituents on fitness of water to be used for domestic purposes.

**Table 3.3: Water quality constituents that affect fitness of use of water for domestic purposes**

| Constituent | Concentration in water<br><br>(g/chl a) | Effects |
|---|---|---|
| **Algae** | Target water quality range 0-1 | Low risk of odour and taste. |
| | 1-10 | For concentration of less than 7µg, there is a slight green colouration of water. Concentrations above this result in a murky appearance and problems of taste and odour especially with blue green algae. |
| | >10 | Water has distinct murky appearance and become increasingly green in colour. Significant taste and odour problems. |
| **Ammonia** | Target water quality range 0-1.0 | No health or aesthetic effects. |
| | 1.0-2.0 mg/.N | Possibility of taste and odour complaints from consumers. |
| | 2.0-10 | Consumers complain of taste and odour. |
| | >10.0 | Unacceptable level in domestic water. Results in fish kills. |
| | 6-10 | Concentrations in this range generally well tolerated although there are rare cases of methaemoglobinaemia in infants. |
| | 10-20 | No effect on adults and Methaemoglobinaemia in infants. |
| | >20 | Occurrence of mucous irritation in adults and cases of methaemoglobinaemia in infants. |
| **pH** | < 4.0 | Severe danger of health effects due to dissolved toxic metals. Sour tasting of water. |
| | 4.0-6.0 | Toxic effects associated with dissolved metals, including lead are likely to occur at a pH<6.Waters slightly taste sour. |
| | Target water quality range 6.0-9.0 | No significant health effects due to toxic metals. |
| | 9.0-11.0 | Increase in toxic effects due to conversion of ammonium to ammonia. Water tastes bitter. |
| | >11.0 | High danger of health effects due to higher levels of ammonia and water taste soapy. |

Source: DWAF (1996a)

### 3.7.6 Effect of water quality on recreational activities

Water used for recreational purpose should meet certain standards. Changes in water quality results in people experiencing health effects such as waterborne diseases, skin and ear infection, carcinogenic risk, human safety risks such as poor visibility of water, aesthetic impacts like changes in water taste, odour, discolouration, staining of clothes and growth of nuisance plants.

## 3.8 Strategies to minimise waste accumulation on aquaculture farms

A number of studies identified several mitigation measures that can be used by aquaculture farmers to minimise environmental impacts of aquaculture. Some of the measures were reported to significantly reduce environmental impacts but some measures were reported to have very little effect on minimising waste accumulation. The waste minimisation measures that can be taken by farmers can be presented in form of a diagram as shown in Figure 3.2

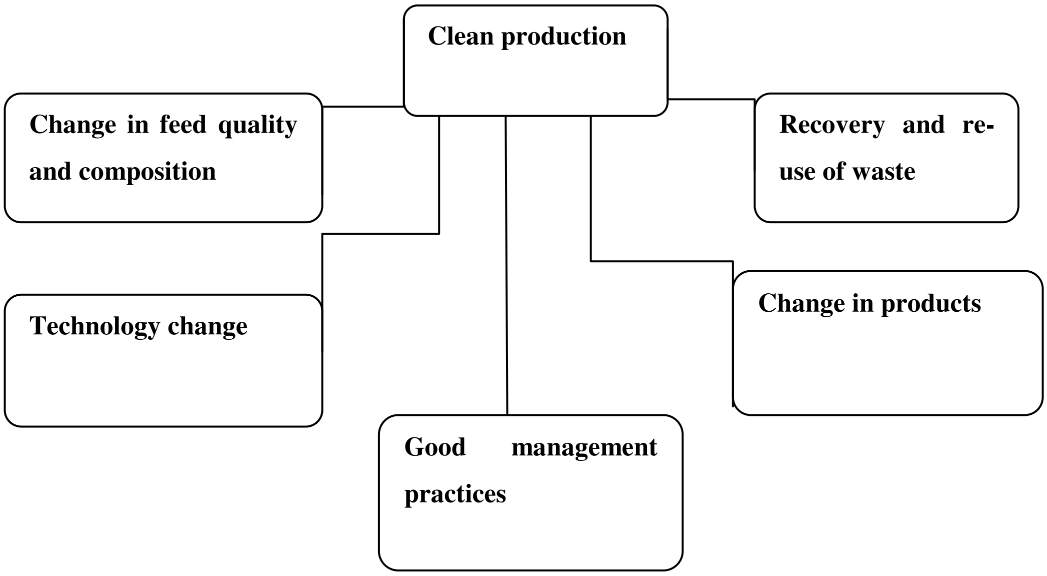



**Figure 3.2**: **Waste minimization strategies**

Source: AquAgris (2009)

The diagram in Figure 3.2 shows the different waste minimisation strategies that have to be implemented in aquaculture in order for aquaculture farms to move to "clean" production. This section presents a review of options potentially available to aquaculture farmers that can be used to reduce environmental impacts of aquaculture.

### 3.8.1 Site selection

Selection of suitable sites for location of net cage systems is an important factor that is mentioned in a number of studies that should be considered to reduce the environmental impacts of aquaculture (Masser, 2007; Maleri, 2007). Before attempting net cage culture, the farmer should ensure that the water body chosen will support the increased biological demand placed upon it. Environmental planning of aquaculture facilities should be based upon the concept of capacity to produce and capacity of the water body to absorb and assimilate waste. Sites chosen for aquaculture should have adequate depth and surface area as well as good water exchange rate to deal with external nutrients added from aquaculture without showing any negative effects (Salie et al., 2008; Masser, 2007). An ideal aquaculture site must have adequate depth to keep fish waste away from the net cage, mantain adequate air circulation through the net cage and reduce chances of weed encroachment around the net cage (Masser, 2007; Maleri, 2007). According to Salie et al. (2008), if a good site is selected, farmers efforts can go into good production management and crisis can be avoided completely. Small scale farmers get technical assistance from the Division of Aquaculture of the University of Stellenbosch in selection of suitable sites. It was also noted that there are strict regulations on authorisation of aquaculture activities, hence proper planning is taken before the farmers are given the green light to develop aquaculture facilities.

### 3.8.2 Production level

In net cage aquaculture, fish waste and uneaten feed is passed into the receiving water body with the expectation that natural processes will remove the waste from water. In such systems, the farmer needs to achieve a balance between the density of fish in each net cage, the number of cages in the water body and the amount of waste the water body can absorb and still maintain acceptable water quality. Stocking rates at each aquaculture site determines the amount of feed to be added into the system hence the amount of organic waste that accumulates at that particular site. Several models have been developed for determining the response of stagnant water to nutrient loading and they have been modified for use in net cage fish farming (Beveridge 1984; Weston et al., 1996). Modelling is an important aspect in planning for aquaculture as models can be used to determine the assimilative capacity of sites that are to be used for aquaculture. Use of models can help aquaculture farmers to determine production levels that can be sustained by water bodies without causing negative environmental impacts.

A number of computer software programmes have been developed to help farmers determine production levels. Farmers in the Western Cape are using AquaEco carrying capacity programme to determine stocking rates based on concentration of nutrients of the dam system as well as site specific conditions of the production site. The most important nutrient that carrying capacity of dams is determined by is based on phosphorus. The computer software programme is used to calculate carrying capacity based on phosphorus concentration of the dam, allowable amount of phosphorus that can be added into the dam water without affecting suitability of water for irrigation and phosphorus that can be added from aquaculture without causing eutrophication. Modelling is very important as it helps aquaculture farmers to calculate the stocking rates of fish that will not cause negative impacts on the environment.

### 3.8.3 Feed quality

Feed is one of the most important and expensive inputs in fish farming. Feed management is of paramount importance to the farmers as it determines profitability of the farm as well as environmental impacts of the aquaculture farm. The main aim of a fish farmer is to achieve optimum growth of fish from the food that is fed (Ghosh, 2000). The amount of organic waste that accumulates at the bottom of the dam depends on the quality of feed used and feed management on the aquaculture farm. Feeding problems common in aquaculture systems include poor quality feed, inadequate feeding, overfeeding and feeding at the wrong time (Cripps & Beirgheim, 2000). Feed quality and feeding regimes play a huge role in determining the quality and potential impact of fish farm effluents (Tarcon & Foster, 2003; Ghosh, 2000). The bulk of the dissolved and suspended inorganic or organic matter contained within the effluents of intensively managed open aquaculture production systems are derived from feed inputs, directly as end products of metabolism or from uneaten feed or indirectly through eutrophication. Farmers are encouraged to use feed from reputable producers with known quantities of nitrogen and phosphorus.

Improvement in pelleting technology has resulted in reduction of feed lost as waste in aquaculture (Cripps & Beirgheim, 2000). Feed pellets sink slowly enabling most of the feed to be consumed rather than wasted hence less pollution. Pelleted feeds are easily assimilated and give good feed conversion rates (FCR) hence their use on aquaculture farms significantly reduces waste output into the environment (Beirgheim & Brinker, 2003). Intense research in feed development has resulted in significant reduction of emissions of waste from aquaculture. Up to now, this has been the only effective approach of reducing discharge of nutrients from open aquaculture systems (Troell et al., 2009). Concetration of nitrogen and phosphorus has decreased significantly over the past three decades as manufacturers are now producing feeds that are better tailored to the dietary requirements of the cultured fish (Ghosh, 2000). Manufacturers have managed to reduce nitrogen from 8 percent reported by Hall et al. (1990) and 2.14 percent of phosphorus (Foy & Rosell, 1991) to 6 percent nitrogen and 1.3 percent phosphorus. It was noted that aquaculture farmers in the Western Cape are using efficient, slow sinking pelleted feed from Aquanutro. The feed contains low concentrations of nitrogen and phosophorus that are formulated based on dietary requirements of the trout fish. In this regard, feed manufacturers have helped in minimising nutrients lost into the environment. The need for farmers to use feed bought from reputable manufacturers is emphasised in the guideline for aquaculture in the Western Cape (Heinrichsen, 2007).

Floating feeds enables the farmers to observe fish feeding and helps farmers to decide when to stop feeding. Feed composition should be tailored to the growth stage of fish with a high content of protein and a minimal amount of carbohydrate so as to promote the health of fish and retain excellent pellet conformation and stability (Masser, 2007). The ingredients of the feed must be highly digestible and lead to low levels of ammonia and suspended solids. When well balanced and stable feeds are used correctly, waste accumulation in dams is controlled and minimised thereby ensuring the long term sustainability of aquaculture. However, dealing with problem of pollution due to feed is not the sole responsibility of the feed producers but also of the fish farmer. Good feeds can be of no use in reducing environmental impacts if the feed is poorly managed.

### 3.8.4 Feed management

Feed management is an important factor in minimising waste accumulation in aquaculture. Beveridge (1996) noted that nutrients (nitrogen and phosphorus) lost into the environment are 2.5 times higher at a food conversion rate (FCR) of 2.0 than with a food conversion rate (FCR) of 1.0. Aquaculture farmers should always strive to reduce FCR as it indicates better feed management practices. Optimum fish size and low FCR indicate that feed applied is utilised by the fish for growth. To reduce feed wastage, there is need to use equipment for waste feed detection. The refinement of feeding strategies in particular the feeding time, frequency and rate also improve production efficiency and minimise waste accumulation (Islam, 2005). The difference in FCR attained on aquaculture farms indicate that feed management is indeed an important factor in reducing environmental impacts of a net cage farm. According to Aquanutro (2010) and Pillay (2004) aquaculture farmers should follow feed management practices mentioned below:

1. Feed the fish, not the water. Trout should only be fed as much as they could consume within about five minutes during feeding time.
2. Daily food allowance should be split into several smaller servings than one feeding per day, allowing fish to consume and utilize the food better.
3. Feeding frequency must be adapted to the fish size that is smaller fish need to be fed more frequently than bigger ones.
4. Adapt particle size to suit the size of the fish that is use bigger particles as the fish mature.
5. Distribute feed over a larger area to ensure availability to all fish in the cage. It reduces variation in fish size and waste, and prevents bullying.
6. Avoid feeding when fish are under stress as they will not eat properly.
7. Feed allowance must be reduced when the temperature or oxygen levels are low or the salinity level is high.

### 3.8.5 Methods of feeding

Method of applying feed on an aquaculture farm is also very important in aquaculture as it determines feed lost as waste. The three methods of applying food to fish are feeding till satiation, automatic feeding and computer controlled strict feeding regimes (Ghosh, 2000). On feeding till satiation, fish can be fed by hand or using demand feeders. The hand feeding technique is the commonly used method of feeding on small scale farms and it requires the farmer to have a good understanding of fish behaviour and feeding patterns in order to reduce wastage of feed. On the other hand the use of demand feeders is an effective way of reducing feed lost as waste because feeding is triggered by fish behaviour. However the main challenge in use of demand feeders is that fish needs to be trained first on use of the feeder and it requires regular observation of feeding habits of fish so as to ensure that the fish are eating.

Automatic feeders that are powered using electricity, batteries or pressurised water systems are also a suitable alternative that can be used by farmers to improve feed management on a farm. The automatic feeders are preset to release a ration of feed at set time intervals. The main problem with automatic feeders is that there is wastage of feed as fish behaviour and feeding patterns change based on factors such as weather. Automatic feeding is more wasteful from feed utilization point of view than feeding to satiation (Ghosh, 2000).

Latest technology in feed management involves the use of strict computer controlled feeding regime that is responsive to changes in the environment (Ghosh, 2000). The system consist of hydrocaustic or video sensors attached to the bottom of the cage to pick up information on presence of uneaten feed that is then send back to the computer, which in turn reduces amount of food fed (Ghosh, 2000). The system reduces feed wastage to 4 percent level and improves FCR (Baird et al., 1996). The improvement in feed technology results in significant reductions of feed wastage and low feed conversion ratios.

### 3.8.6 Feed storage

Feed storage plays a big part in reducing the amount of feed that is lost as waste in cage aquaculture. Fish food should be kept and fed to the fish fresh so that the fish can consume most of the feed thrown into the cage. The palatability and acceptability of the food to the fish is of critical importance for complete consumption, good growth and consequently optimal health and vitality. If fish utilize most of the feed administered, then waste accumulation due to uneaten feed will be significantly reduced.

### 3.8.7 Site fallowing

Allowing for a fallowing period between production cycles is a common method that has been used in marine aquaculture to allow solid waste from net cage systems to degrade naturally or erode and the benthic plants to recover (Beirgheim, 2007). The non-production period on a cage farm that allows recovery of benthic community depends on the size of the farm with the reported periods ranging from six months on small aquaculture farms to four years on large aquaculture farms (Islam, 2005; Beirgheim 2007). However, there are several disadvantages that have been noted on using this approach. Site fallowing can be unpopular with farmers due to the loss of production potential, possible negative impacts on fauna and negative public perception (Islam, 2005). Scotish Environment Protection Agency (SEPA) also noted that recommencement of production at fallowed sites results in rapid souring of the benthic environment (Annonymous source, 2010). In instances where cages are to be shifted to new sites, the possibility of using such a method depend on flexibility of the net cage structure as well as the size of the area where farmers are allowed to set their cages. Site fallowing is therefore only regarded environmentally beneficial when the level of existing effects is high and benthic community is allowed time to recover.

## 3.9 Methods of enhancing natural degradation of waste

A number of methods have been investigated on their ability to increase natural degradation of waste falling off from net cage farms. In most of the methods tried, the main aim was to increase circulation of oxygen on the benthic community for natural breakdown of waste by action of aerobic bacteria. Providing a large surface area for autrophic bacteria to grow is the best way to convert ammonia to less toxic forms (Islam, 2005). The methods investigated include placing a screen device beneath the net cages, placing reefs beneath the net cages, pumping oxygenated air to the benthic community and harrowing of seabeds to allow oxygenated water into the sediments (Burynuik, 2006; Angel & Spanier, 2002). The different approaches have either little effect or are impractical as noted by Angel and Spanier (2002).

### 3.9.1 Screening device beneath the net cage systems

A screening device made up of mesh can be placed beneath the net cage system and fish farm effluents collects on the screen for natural breakdown or onsite treatment. The method is based on the concept of screening devices that have been used in land based systems like ponds for collection of solid farm effluents (Makinen et al. (1988) cited in Burynuik et al., 2006; Beirgheim & Forsberg, 1993). Clogging rapidly of the screen occurs if concentrations of suspended particles are too high or as with the case of fish waste, the material tends to be adhesive (Cripps & Beirghem, 2000; Wheaton (1985) cited in Burynuik et al., 2006). If a screen device is placed beneath a net cage system, the clogging that is a problem for land-based treatment would be used to an advantage to enhance retention of solids on the screening device. The choice of a screen used is site specific and dependent upon depth beneath the net cage, currents and topography. Careful analysis of the size of particles that fall through the cage is important as the mesh size of the screen should be small enough to retain most of the waste.

The rate of organic waste degradation on the screen is expected to be higher than the benthic rates. Solid waste surface area exposed to dissolved oxygen is higher on the screen (both sides of the screen) and dissolved oxygen and water temperatures under the net cage are slightly higher than at benthic level (Burynuik et al., 2006). Benefits of the proposed method include compatibility with net cage system, collection of dispersed waste and an increase in degradation rates and recovery times as compared to the conventional fallowing periods. However, the use of screening device has its own negative aspect as it does not remove the waste quick enough before it breaks down hence the problems faced due to dissolved nutrients might continue to be experienced. The breakdown of waste on the screen poses a threat to the concentration of oxygen in the water (Burynuik et al., 2006). Problems associated with shortages of oxygen might be noticed due to the increased oxygen demand by aerobic bacteria that decompose the waste on the screen.

### 3.9.2 Artificial reefs beneath cage systems

Closely related to the use of a screening mesh below a net cage is the method of placing artificial reefs beneath the net cages investigated by Angel and Spanier (2002). Artificial reefs made of porous high density polyethylene fence material can be placed beneath the cage systems to increase the total surface area of waste exposed to aerobic microbials for natural decomposition. Organic matter decomposition is enhanced since natural degradation is a function of microbial processes and aerobic micro-organisms that are more efficient than anaerobic ones (Cowie & Hedges; cited in Angel & Spanier, 2002). Increased circulation of oxygen and increased surface area of waste exposed to bacteria speeds up the natural breakdown of waste and reduces impacts of waste from net cage farming on benthic organisms. Results obtained by Angel and Spanier (2002) suggest that the reefs could act as biofilters to alleviate organic loading on net cage aquaculture farms. Reefs attract a large number of wild demersal fish and other invertebrates to the region to consume the feed on the reefs (Angel & Spanier, 2002). However, the use of screening devices and reefs can also cause negative effects on the fish farm due to the increased oxygen demand for aerobic decomposition as amount of dissolved oxygen is an important factor for fish survival on a fish farm. The approach only reduces accumulation of organic waste but it increases the concentration of dissolved nutrients hence it might cause eutrophication in water bodies.

## 3.10 Mechanical methods for removing waste

A net cage system is made up of a floating collar that is rectangular in shape, a suspended net bag and a mooring system. The structure has walkways and the net cages are connected to each other using ropes and shackles to form a floating rectangular shape of individual cages (see Appendix 6). Waste recovery devices can be placed beneath the net cage to collect and recover waste. The following mechanical devices have been designed and used to collect waste falling off the net cage systems.

1. Cage Waste Collection and Recovery Device (C.A.W.A.C.O.R.E) designed in Italy
2. Lift-up dead fish and waste feed collector.
3. Viking fish model by the Sweedish Company (Viking Fish AB).
4. Refta lift-up pellet sampler by Nowergian Company.

(Barbarto et al, 2004; Enell & Lof, 1984; Braaten 1992; Ackerfos, 1994)

### 3.10.1 Cage Waste Collection and Recovery Device

Cage Waste Collection and Recovery (CA.WA.CO.RE) device was designed and used to collect and recover organic waste from net cage aquaculture systems in Taranto Mar Piccdo (Puglia) (Barbato et al., 2004). The device collects and recovers waste that accumulates beneath a net cage and reduces the long term negative effects of waste on the receiving environment. The system consists of a rigid frame with an attached funnel shaped lining which collects the waste and a waste recovery apparatus equipped with compressed air. The system is fitted with an air suction lift tube that recovers the waste and removes the waste from the water. The air lift suction tube ensures that solid waste is quickly removed and recovered before it dissolves in water.

The device can be placed either beneath an existing net cage or included in a new net cage structure. Fast recovery of waste by the system ensures that water quality is maintained and reduces oxygen demand for decomposition of the waste. The device also effectively reduces incidences of burrowing of important micro-organisms and covering of benthic plants and organisms. It confines waste to a small space beneath the cage and prevents dispersion of waste. The recovered waste can be converted to other products that are of economic value e.g. in making composts or fertilizers that can be used in vegetable production. However the device can only recover particulate waste and dissolved nutrients are lost into the environment.

### 3.10.2 Lift-up dead fish and waste feed collector

It is a system that was designed in Norway that can be used to collect dead fish and uneaten feed waste coming from a net cage system. A Lift-up dead fish and waste feed collector comprise of a fine meshed net cloth placed under the net cage to which a tube is attached at the bottom to remove dead fish, excess feed and large faecal particles (see Appendix 5). A compressor delivers compressed air into the collector. The waste is collected using the air lift and passed through the filtration unit that retains the particulate waste (Ackefors, 1997). The system is known to collect up to 100 percent surplus feed, size 6mm and larger and nearly 70 percent of 4mm particles (Ervik et al., 1994). The advantages of using the system are that: it is fast, simple and efficient in removing morts; reduces spread of bacteria and virus; ensures better feed control and less feed waste; improved fish growth; prolonged life span of fish farm sites; can be mounted while there is fish in the net cage and prevent predators feeding on morts. The high cost of the system is balanced by the benefits of clean environment (Ghosh, 2000). Studies by Hall et al. (1990), Enell and Ackefors (1991) indicated that 25 percent of nitrogen and 75 percent of phosphorus wastes from aquaculture appear in particulate form. The Lift-up dead fish and waste collector recovers approximately 80 percent of particulate waste (Ghosh, 2000), hence waste recovery using the system is based upon the following assumptions:

1. 25 percent of nitrogen wastes from open net cage systems appear in particulate form
2. 75 percent of phosphorus wastes from open net cage system appear in particulate form
3. 80 percent of particulate matter emitted from the net cages are collected by the Lift-up system

Based on the assumptions mentioned above and nutrient loading derived from mass balance models, the recovery of nutrients using a Lift-up dead fish and waste collector can be calculated using the following formula:

$$R=NL*(P/100)*r/100$$

Where

R-recovery of nutrient
P-Percentage particulate form
r- Percentage recovery
NL-Nutrient load

Source (Ghosh, 2000)

The Refta lift-up pellet sampler and Viking tube are similar in design to the Lift-up system.

### 3.10.3 Dredging of organic waste from the dam floor

Collection of waste from dam floors or sea floors can be done using dredging machinery. Dredging machinery can be used to relocate the sediment materials from a dam system down stream or deposit it outside the water body (Bray, 1979). Dredging can be carried out in two different ways, either by drawing down the water and use conventional wheel or chain driven machinery to remove sediment from a dry bed or use submersible machinery for dredging in dam with water. The second method of dredging does not require dewatering of the reservoir. It involves dredging of submerged material using barges with different equipment. Use of dredging machinery is impractical, inefficient and a significant potential risk to the environment (Anonymous source, 2010). The process of collecting waste would cause resuspension of a significant amount of waste therefore collection of all the waste will not occur (Anonymous source, 2010). Use of this method requires transportation of the material from water to land, dewatering of the removed waste before transporting by truck and the total costs depend on the distance to the disposal site from the dam. The action of dredging to remove organic waste beneath a net cage is likely to cause more harm to the environment than benefits so it is not applicable to net cage systems.

### 3.10.4 Saxophone sediment sluicer

The equipment comprise of a saxophone shaped sluicer head mounted to a pipeline. It sucks sediments from the surface of the deposit. The saxophone is permanently fixed near the reservoir bed and sediments are allowed to deposit over it (Jacobsen, 1997). The driving force is the head of water between the reservoir surface and outlet level. This method is ideal for removal of organic waste as the sluicer can be fixed directly beneath the net cage system and used to suck out all the organic waste that will be falling off from the net cage. The system evacuates deposited sediment from reservoirs by sucking a liquid/solid mixture from the bottom of the reservoir (Sangroula, 2007).

### 3.10.5 Flushing

Flushing is a widely used method used to regain storage volume of water reservoirs and can be used to remove waste from aquaculture. The method involves opening of low level outlets (gates) and drawing down the water surface elevation behind the dam to temporarily re-establish river flow along the impounded area (Bray, 1979). The flowing water remobilizes the sediments and flushes them out of the reservoir through the outlet thereby transporting sediments from upstream and depositing them downstream. The flushing method has been proven to be a technically feasible method and it is also a sustainable option that can be used to restore capacity of water reservoirs (Bray, 1979). However, this method can only be applied where there is transport capacity of the flow itself where sediments are flushed out from up stream to down stream without using external energy. Its success depends on water level in the reservoir during the process and it can be carried out effectively if water level in the reservoir can be kept low for some time while the flow rate is high (Jacobsen, 1997). Flushing out sediments during the flooding period can be very useful to farmers as all the sediments can be removed including organic waste from the aquaculture facility.

Although the method has proved to be feasible and effective in removing sediments, it comes with a number of disadvantages or negative effects. Its application means that a substantial amount of water is lost through the process and the situation is not ideal in irrigation dams as the water is required for irrigation, especially in the Western Cape where water is scarce. The process also requires drawdown of the reservoir and interruption of water supply that might affect farm operations and the ecosystem. Flushing can also damage the net cage system structure and sediments flushed out settles downstream where they may cause several ecological effects. The fine sediments that settle down stream may cover coarse bed material which is an important living space for small organisms.

### 3.11 Semi-Intensive Floating Tank System (SIFTS)

A semi-intensive floating tank system is a fish production system that was designed in Australia by Ian Macroberts (Mcrobert Aquaculture Systems) for use in saline water for fish production. The system comprise of floating cylindrical tanks that are made of fibreglass. The floating tanks are placed in a dam forming a square shape supported on the sides by a floating platform (see Appendix 4). The tanks provide buoyancy to the structure as well as a working platform to the tank. The top of each SIFTS floats 100mm above the pond water and air lift pumps are used to pump water into the tanks at a rate of 330L of water per minute as described by Partridge et al. (2005). Water in each SIFTS tank is exchanged up to four times per hour, enabling fish stock densities of up to 100kg/m$^3$ (depending on species) to be cultured without the use of pure oxygen (Partridge et al., 2005).

The two air-water lift pumps on each tank move large volumes of highly aerated water through each tank continuously. The pumps are powered by electricity on shore and air is fed via a pipe to the anchored tanks. The tanks rely heavily on air to keep the water clean and well maintained. Constant circulation of pumped in water creates centripetal force that helps concentrate solids in the centre of the tank (Partridge et al., 2005). Solid waste is then sucked out using a patented vertical waste arm and channelled to a sludge collector on the side of the tank. The sludge collector is located close to the source of the waste resulting in quick removal of waste in 90 seconds, before it has time to breakdown and deteriorate water quality (Partridge et al., 2005). Quick removal of waste also helps in feed management as feeding stops when feed starts to appear in the waste collector. With solids removed, the rest of the water is then returned to the water body for the natural ecosystem to take care of (Partridge et al., 2005). The SIFTS system is an alternative water based production technique that can be used in place of net cages that effectively removes waste produced on aquaculture farms.

### 3.12 Biological waste recovery (nutrient recycling)

Development of sustainable aquaculture systems depends on use of clean production techniques based on principles of minimum nutrient or waste loading on the surrounding aquactic environment. Several studies have indicated that production of waste from aquaculture systems cannot be avoided but a clean system can either remove waste mechanically or use it up within the production system (AquAgris, 2009; Barrington et al., 2008; Troell et al., 2009). An intergrated aquaculture system (polyculture) is whereby a number of aquatic organisms are produced together in a single water body. The use of intergrated system offers an alternative system of dealing with waste from aquaculture farms by moving away from the usual method of dilution of waste to one of conversion of waste. Intergrated systems combine fed aquaculture fish species (e.g. finfish) with inorganic extractive species (e.g. seaweeds) and organic trophic level species (e.g. mullet) (AquAgris, 2009; Chopin et al., 2008; Troell et al., 2009). Species used in intergrated system display complementary feeding behaviour and occupy distinct niches within the system (Whison, 2000; AquAgris, 2009; Casalduero, 2003). Chopin et al. (2008) noted that the main issue in effective implementation of intergrated systems is in their optimal functioning which requires an in depth understanding of the physiology and nutrition of selected species. There is need to quantify the rates of production and consumption of excess nutrients by the fish and the extractive species (Shpigel, 1993; Casalduero, 2003). Use of intergrated systems is an effective way that can be used by aquaculture farms to convert waste produced from aquatic farms into valuable products.

Literature show that there are a number of studies where theoretical models have been developed of hypothesised farms of intergrated multi-trophic level aquaculture systems to deal with the problem of waste accumulation on aquaculture farms (Troell et al., 2003; Troell et al., 2009; Beirgheim, 2007; Tarcon & Foster, 2000; Ghosh, 2002). In Canada and China, there are reported cases of full scale intergrated farms that are in operation (Troell et al., 2009). At Bay of Fundi in Canada, a full scale marine intergrated farm is producing salmon, kelps and blue mussel (Troell et al., 2003). Enander and Hasselstrom (cited in Chopin et al., 2008) reported successful intergration of prawns, mussels and red algae where they recorded a reduction in effluent of 81 percent for ammonium, 19 percent for nitrate, 72 percent for total nitrogen, 83 percent for phosphorus and 61 percent total phosphorus. In this study, a model intergrated aquaculture farm was developed and compared with other production techniques as an alternative way of dealing with waste.

The concept of intergrated aquaculture is well known in freshwater aquaculture particularly in Asia where the system has been successfully used to mitigate excess nutrient and organic waste generated from intensive fish production (Troell et al., 2003). Intergrated aquaculture in fresh water have been practised in Asia particularly China for over 1000 years with reported cases of several species cultured within a single water body (Whisson, 2000; Blackely & Hrusa, 1989, Pillay & Kutty, 1993). The first experience of intergrated system in lakes was the farming of fish and aquatic plants in Tai in China (Chang, 1987 cited in Casalduero, 2003). However, most of the studies from Asia were based on trial and error and there are few publications on species used (Whisson, 2000). In some published reports of intergrated freshwater aquaculture, the investigations involved culturing of two species (Whisson, 2000; Lupatsch et al., 2003; Prugnin et al., 1975; Whitmarsh et al., 2006). The availability and suitability of species that can be used in the intergrated system is one of the main challenges that need to be investigated for successful establishment of intergrated fish farms.

Skaar and Bodvin (1993) suggest that intergrated systems are only effective in enclosed systems if all the dissolved and particulate waste from the farm is to be utilised within the system. However, there are also reported cases where intergrated aquaculture has been used in open net cage systems to deal with waste. Lupatsch et al. (2003) reported faster growth of grey mullet as a secondary species to improve sediment quality in net cage systems for freshwater aquaculture. Wurts (2010) reported the possibility of intergrating paddle fish, tilapia and mussels in ponds. Whitmarsh et al. (2006) found out that appropriately sited mussel lines could help in removing a portion of dissolved waste produced from a net cage farm. Growth of mussels at sites in close proximity (10m) to fish net cages was found to be significantly higher than at sites further away (Whitmarsh et al., 2006), indicating that mussels utilised nutrients released from the aquaculture farm. A theoretical model presented by Bodvin et al. (1996), indicates possibilities of producing marine species salmon, blue mussel and seaweed in floating closed bags. The floating closed bag system have been developed and successfully used in Norway and Canada (Troell et. al., 2009; Ghosh, 2000). However, the closed nature of the bag system means that the fish stock would be at high risk in the event of pump failure and there is also a risk that the bags would tear in extreme weather conditions causing fish escapees (Annonymous source, 2010). Net cages and closed bags are designed in much the same way with the only difference being that in net cages, nets are used to confine fish while in a closed bag, bags are used to confine fish within a frame. In this study, the modelled farm can either use nets or bags as the capital required for the cages is the same.

In South Africa, minimal research on intergrated aquaculture has been carried due to the fact that aquaculture is still a fairly new industry. Proposed candidate fresh water species that can be successfully intergrated with trout in the Western Cape include freshwater mullet, fresh water mussels (blue mussels) and cray fish. Fresh water mullet and fresh water mussels (blue mussels) are marine species but in the course of their life cycles they enter fresh water rivers hence they can be successfuly cultured in freshwater (Wurts, 2010). Succesful intergration of mullet with tilapia and trout has been reported (Hafez, 1995; Whisson, 2000, Lupastch et al., 2003). The candidate species are detritus i.e. they feed on organic material such as bodies or fragment of dead organisms as well as faecal material hence their suitability for intergration with trout to feed on uneaten feed waste coming from trout cages. Prugnin et al. (1975) reported successful intergration of trout with gray mullet in Israel, with mullet feeding on waste trout feed.

In addition to conversion of waste, intergrated fish production technique also reduces risk for the aquaculture farmer as it offers a diversified product profile for farmer in an environment of changing prices of one farmed species (Chopin et al., 2008, Whisson, 2000). Production of fish and extractive organisms that are of economic value can translate into higher profits for the farmer and if suitable species can be identified, the extra income can act as an incentive for farmers to adopt intergrated production systems. The main challenge in fresh water aquaculture is to find suitable aquatic plants especially in dams where they can be regarded as nuisance plants that affect irrigation equipment. Studies from land based and open water systems confirm that nutrients released from aquaculture are suitable for macroalgae or vegetable production (AquAgris, 2009). The concept of hydroponics (vegetable production using waste water from aquaculture) and floating vegetable gardens can be used in intergrated system and vegetables can be used as extractive species that utilises dissolved nutrients. Barrington et al. (2008), noted that intergrated systems are biological acceptable, economically viable and socially acceptable, hence in this study, the intergrated system will be compared in its effectiveness to recover waste with mechanical methods.

### 3.13 Valuation of benefits of improving water quality in dams.

In this study, a cost benefit analysis was carried out to compare the proposed alternative aquaculture production techniques that can be used by aquaculture farmers to deal with the problem of waste accumulation from aquaculture farms. The most important attribute of carrying out cost benefit analysis on the alternative production techniques that can be used by aquaculture farmers is for decision making purposes as for any feasible project, the benefits accrued by the society regardless of who accrue them should be in excess of the estimated costs. In this study, although a financial analysis gives a good indication of viability of small scale trout farming using different production techniques, environmental and social benefits that result from recovering waste from the dams are not reflected in the financial analysis. In order to determine the economic value of maintaining good water quality in dams that are used for aquaculture, it was necessary to estimate benefits and costs that are not reflected in the financial analysis. The benefits that arise are the good or desired effects contributed by the proposed aquaculture production techniques and the costs are the undesired impacts. A cost benefit analysis in practice considers whether a change from given conditions would present a desirable shift rather than seeking a full optimum solution (Young, 2005).

In a cost benefit analysis, the impacts of alternative aquaculture production techniques on water resource use are specified in terms of the economic value using a common measure that is money. The economic value is determined by the impact on social welfare, which is given by the aggregate impact on the utility of individuals in society (Burke et al., 2004). The utility to individuals is determined by their preferences, which individuals express in the amount that they are willing to pay for the conservation or improvement in quality of water, as well as individuals' loss of welfare owing to water degradation or quality decline (Sutherland & Walsh, 1985). Individuals' preferences are measured in terms of how much they are willing to pay, which is also referred to as the economic value or benefit. Water in irrigation dams like any other environmental good offers a range of services or benefits that need to be valued in order to determine its economic value. In this study it was important to determine the costs and benefits of good water quality in farm dams so as to give a bigger picture to fish farmers that although their current production techniques of farming are financially viable, recovery of waste from dams will generate more benefits than reflected from financial analysis of fish production using the alternative trout production techniques.

The concept of "value" of water have been argued and developed over the years by many economists. In order to understand the phrase 'economic value of water', it is important to first define the term "value" The term value is defined from the dictionary as reffering to importance or desirability of a good. Adam Smith (cited in Hanemann, 2005) explained the two different meanings of value in his paradox of water and diamonds. He made a distinction between the two meanings in the following passage found in his great economics classic "Wealth of Nations":

*"The word value, it is to be observed, has two different meanings, and sometimes expresses the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called value in use; the other, value in exchange. The things which have the greatest value in use have frequently little or no value in exchange; and, on the contrary, those which have the greatest value in exchange have frequently little or no value in use. Nothing is more useful than water; but it will purchase scarce anything; scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it" (book I, chapter IV).*

In the passage, Adam Smith made a distinction between two different meanings of value as value in use (*expresses the utility of some particular objects*) and value in exchange (*expresses the power of purchasing other goods which the possession of that object value in use conveys*). Based on the distinction on two different values made by Smith, economists further developed the concept by coming up with techniques that can be used to place monetary values on environmental goods and services. In this study, the aim was to determine the "value in use" of good water quality in dams that are used for multiple purposes including fish farming.

In many instances market price (financial value) have been used as a measure of the "economic value" of water, a notion that was argued by Hanemann (2005). He noted that if market price is used to measure the economic value, then the concept of economic value will only be restricted to marketed goods and will be different from the way people understand it. In instances where water has been allocated in markets, usually a low price has been attached to it despite its importance in supporting life. Water as an economic commodity that is different from other commodities helps in explaining why price does not in general measure economic value as it is a valuable resource although it cannot be traded in the market (Perry et al, 1997). The price of a good or service and its economic value are distinct and can differ greatly as water can have a very high value, but a very low price or no price at all (Burke et al., 2004).

The most common measure that has been used in placing monetary values on economic value of water is the concept of Willingness to Pay (WTP) and Willingness to Accept (WTA) (Hicks, 1939; Henderson, 1941 both cited in Hanemann, 2005). Willingness to Pay (WTP) is a measure of what people would be willing to trade off for specific improvements in the environment that can be expressed in monetary terms and willingness to accept is a measure of what people are prepared to accept in order to allow for specific degradation of environmental good or services (Burke et al., 2004). Water as a commodity has a great value in use but very little value in exchange. In revealing their willingness to pay, the farm community indicate their desire to have cleaner dam water, cleaner underground reservoirs (reduction of risks from nitrate pollution of ground water) and a cleaner environment in general. The individual response on willingness to pay for clean up of water were collected and aggregated to a total value directly dependent on the number of individuals affected.

### 3.13.1 Marginal value versus average value

Water is a neccessity of life and households already have some access to water. In any economic valuations of water where there are to be policy interventions that involve changes in quantity or quality of water, the interventions will only change access rather than transform the situation from no access to some access, hence the relevant quantity that was estimated in this study was the marginal value of water rather than average/total value (Hanemann, 2005). In a cost benefit analysis of pollution control programmes, it is possible to compare the value of what society members receive from an improvement in a given fresh water system with the values of what its members give up to degrade the same system. Benefits are an estimate of marginal value i.e. changes in value resulting from specified change in an ecosystem service (Goulder & Kennedy, 1997 cited in Leyva & Sayachi, 2005; Dixon et al., 1994). In this case of measuring benefits of improving water quality, people already have access to the water, so what was measured was the change in water quantities used as a result of the proposed changes to water quality.

In addition to quantity, quality of water influences its economic value. Water quality can be viewed as a public good and like most public goods, environmental goods in particular, markets do not exist therefore the benefits associated with improvements in water quality are difficult to measure. In attempting to overcome these problems, economists developed several approaches for valuing non-market environmental goods (Mitchell & Carsons, 1989; Carsons, 2000; Hayes et.al, 1992; Young, 1996). Non-market economic valuation techniques can be used to calculate shadow prices that reflect the economic value of water in place of market prices (Young, 1996). The following techniques have been used to determine the economic value of good water quality in several studies (Dixon et al., 1994; Leyva & Sayachi, 2005):

1. Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of pollution control programmes. In maintenance of good water quality, putting in place measures to reduce effluent loading in dams reduces the costs that would be required to clean up the water if there are excess nutrients released into the water source.
2. Replacement Cost (RC): services could be replaced with man-made systems. For example, nutrient cycling waste treatment can be replaced with costly treatment systems. However, people have to note that although it might be possible to clean up water to meet standards for different uses, it is not possible to clean up polluted water to meet the standards for ecosystems in dams.
3. Net Factor Income (NFI): services provide for the enhancement of incomes: for example, water quality improvements increase aquaculture production and incomes of aquaculture producers.
4. Travel Cost (TC): service demand may require travel, whose costs can reflect the implied value of the service. For example, if dams are used for recreational purposes and attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it. Travel cost methods have been used primarily to estimate value of water quality changes at recreational sites.
5. Hedonic Pricing (HP): service demand may be reflected in the prices people will pay for associated goods: for example, housing prices along the coastline were there is good water quality tend to exceed the prices of homes in coastlines where there is poor water quality.
6. Contingent Valuation Method (CVM): service demand may be elicited by posing hypothetical scenarios in surveys that involve some valuation of changes in water quality. For example, people would be willing to pay for increased preservation of beaches and the shoreline.

### 3.13.2 Water quality valuation using Contingent Valuation Method

Social benefits of dam or in-stream water quality improvements are often difficult to quantify for possible cost justification in pollution control programmes. The difficulties arise from that many service flows of water quality are not channelled through the market system to consumers and producers (Chen et al., 2005). Many water quality management programmes simply assess the financial outlays derived from the market without regard to possible non-market benefits and costs (Hayes et al., 1992). Such cost benefit analysis is defective without considering monetary values for the non-marketed environmental resources or service flows. In order to incorporate non-market benefits of water quality improvement if 'clean' production techniques are adopted and used by aquaculture farmers, this study used the contingent valuation method (CVM) to estimate consumers' willingness to pay for improvement of water quality to meet different use categories.

The CVM method is a survey based method that is usually used for placing monetary values on environmental goods and services that are not bought or sold in the market place (Carson, 2000; Hayes et.al, 1992; Chen et al., 2005). It is a method that can be used to estimate use and non-use values of environmental goods and services. CVM has been used for eliciting the value of several aspects of water resources including water quality, recreation and biodiversity (Burke et al., 2004; Chen et.al, 2005). Farber (1988), Burrows and House (1989), Smith and Davies-Colley (1992), Goffe (1992) (all cited in Chen et.al (2005) and Hayes et al., (1992), discussed public perception of water in rivers and coastal systems with respect to suitability for recreational use by a contingent valuation method. A contingent valuation questionnaire presents a scenario of a fresh water ecosystem and a hypothetical market in which the benefits associated with changes in water quality might be purchased. Hayes et al. (1992) noted that CVM assumes that people would respond to the hypothetical market in the same way that they do in a real market transactions. CVM allows for inclusion of non-users in the study thereby allow to measure intrinsic benefits (i.e. option value, existence value and bequest value). In this study ex-ante analyses was used where respondents were asked to value improvements in water quality before they actually occur (Hayes et al., 1992). Benefits expected to arise from improved water quality when 'clean' aquaculture production techniques are used were evaluated using the CVM. The values revealed by respondents are thus said to be contingent upon hypothetical markets presented in the survey instrument.

Although there are thousands of cases where the CVM was used, the method remains the subject of heated debate within the non market valuation literature (Hanemann, 1985). Portney (1994) noted that the main problem in using CVM is that many economists remain wary of hypothetical transactions to reflect how people would behave in a functioning market. Controversy that surrounds the use of CVM is centred on that respondents are inconsistent with the assumptions of rational choice that is respondents may not understand what it is they are being asked to value. Respondents fail to take contingent valuation questions seriously because the results of the surveys are not binding and raise objections as well. Arrow et.al (1993) put foward that it is also difficult for CVM surveys to provide adequate information to respondents about the policy or programme for which values are being elicited and the researcher should ensure that respondents have absorbed and accepted information as the basis of their responses. Mitchell and Carson (2000) noted that although this method is surrounded by controversy, it still remains a good method of determining the value of benefits of environmental goods that are not traded in the market. Arrow et al. (1993), Mitchell and Carson (2000) suggested that, if a contingent valuation study is carefully designed and carefully implemented, the method can give a good estimation of environmental benefits that will be expected by a certain course of action that intends to be implemented. The CVM method was used to determine the benefits of maintaining good water quality in irrigation dams.

To address biases of CVM, the Blue Ribbon Panel under the auspices of U.S. National Oceanic and Atmospheric Administration (NOAA) (Arrow et. al., 1993) outlined several guidelines that were followed in this study to ensure that a CVM study estimates the environmental benefits of removing waste discharged from aquaculture farms from dams. Much emphasis in this study was placed on careful designing of the CVM study in order to overcome most of the issues that have raised controversy in implementation of CVM. The questionnaire designing process was carried out in the following seven steps:

1. Identification and specification of information to be evaluated.
2. Determination of the population and sampling methods to be used.
3. Development of scenarios or hypothetical situation.
4. Preparation of questionnaire.
5. Implementation of pilot test.
6. Implementation of the full scale survey.
7. Analysis of the study results and estimation of WTP.

### 3.14 Summary

This chapter presented the concept of sustainability and its application to aquaculture. The concept of sustainability is very important in development of aquaculture farming and it requires aquaculture farmers to adopt production techniques that are economically viable, environmentally sustainable and socially acceptable. In order to attain environmental sustainability on aquaculture farms, planning of the farms based on nutrient loading models is an essential tool in estimating and predicting the path of nutrients added as feed in aquaculture farms. A better understanding of nutrient loading is neccessary in order to choose the production techniques to be used by aquaculture farmers to recover waste from aquaculture farms. Effluent from aquaculture has a potential to affect use of dam water as a multi-purpose resource. Aquaculture production has to seriously consider reducing environmental impacts in order to maintain good water quality in dams so that it can be successfully intergrated into dam uses. There are a number of strategies that can be implemented by farmers to minimise waste. The approach taken in order to move towards clean production systems include use of feed from reputable suppliers, good farm management practices, adoption of production techniques that reduce waste, recovery and recollection of waste. The benefits that arise from 'clean' production in aquaculture are usually environmental and social benefits that are not reflected in financial analysis of production techniques that need to be valued using environmental valuation techniques.

# CHAPTER 4

# RESEARCH METHODS

## 4.1 Introduction

According to Leedy (1997), research is a process by which we apply a variety of standardized methods to get demonstrable facts that will help in answering the questions or find solutions of a problem. In pursuit of valid knowledge, this research made use of standardized methods to gather and analyse both primary and secondary data that was used to test the hypothesised situations. The following section describes the methods that were used to collect data that was used to resolve the four fundamental questions i.e. what data was needed, where the data was collected, how was the data secured and how the data was interpreted.

## 4.2 Secondary data collection

The secondary data required for this study was collected through conducting an extensive literature survey that included reviewing literature from articles that are published in journals, books, conference papers, post graduate theses and articles from the internet. Production techniques and mitigation measures that can be used by aquaculture farmers to minimise environmental impacts of aquaculture were identified from literature. The identified production techniques were assessed on their suitability and transferability for use in South Africa by small scale aquaculture farmers. Methods that were suitable and transferable to small scale aquaculture were adopted and models of typical small scale farms using the techniques were developed. Additional secondary data was obtained from the following organisations that are involved in development of aquaculture in South Africa: Aquaculture Institute of South Africa (AISA), Western Cape Trout Association, Department of Agriculture and Forestry (DAFF) (Western Cape), Department of Water and Environmental Affairs (DWEA), Division of Aquaculture of the University of Stellenbosch, Three Streams Smokehouse and Hands-On Fish Farmers Cooperative. Most of the secondary data was obtained through sending e-mail request for the data as well as internet downloads of required information from the mentioned organisations websites.

## 4.3 Primary data collection

Leedy (1997) defined primary data as the data that lies closest to the source of the ultimate truth underlying the phenomenon. In this study, a survey research was used as the primary data collection method. The problem investigated in this study was based upon research that was carried out previously in the study area that showed that the use of farm irrigation dams as multi-purpose resources is possible, but there is need to maintain good water quality in the dams if all the activities are to be sustainable. Results of previous research in the study area carried out by Maleri (2007) and Du Plessis (2007) showed that farmers do sometimes experience water quality related problems on their farms. The purpose of this study was then to identify production techniques that can be used by the small scale trout farmers to remove waste coming from aquaculture farms to ensure long term sustainability of small scale trout production in irrigation dams.

### 4.3.1 Data collection from small scale trout farmers

Based on literature and secondary data that was obtained from organisations involved in aquaculture, it was noted that additional data was required from small scale farmers in order to develop models for farms where identified production techniques could be used to remove waste. Two questionnaires were designed to collect additional information from small scale trout farms using net cage production system and farm households respectively. The small scale trout farm questionnaire (see Appendix 1) comprised of seven sections: Section 1, solicited for background information of the aquaculture farm; Section 2, solicited for production information and Section 3, collected information on marketing of the fish produced from the aquaculture facility. Section 4 collected information on human resources on small scale aquaculture enterprises. Section 5 collected information on environmental issues, while Section 6 collected information on the farm inventory and waste minimisation strategies currently being used by farmers to minimise waste accumulation. The last section, Section 7, included questions on farmers' views on alternative production techniques identified from literature. Pictures of alternatives techniques and explanation of the production techniques was done to help farmers understand questions in Section 7 and give their opinions.

Contact details of thirty small scale net cage trout farmers that are members of the Hands-On Fish Farmers Cooperative were obtained from the cooperative. Twenty three farms out of the thirty were in operation for the 2008/9 fish production season as seven had stopped production due to various reason. Visits to all small scale trout farms in the Western Cape could not be done due to various constraints but in order to get a representative overview of the problem at hand, interviews were conducted on ten small scale trout farms across the Western Cape (Worcester, Wolseley, Franschhoek, Botrivier, Paarl and Stellenbosch). On choosing the farms to be visited, four factors were considered and these were resources, time, money and geographical location. The researcher visited the small scale trout farmers together with the assistant technical manager of the Hands-On Fish Farmers Cooperative and questionnaires were completed through personal interviews with farmers. Personal interviews enabled the researcher to discuss a number of issues with the farmers on the production techniques available that can be used to minimise impacts of aquaculture farms on dam water. Additional information on prices of fingerlings and feed was obtained from Three

Streams Smokehouse, a processing company that buys rainbow trout from the small scale farmers. Additional information on production techniques was also obtained through contacting distribution agents in countries where the techniques were designed.

Based on information collected, a model of a typical small scale net cage trout farm in the Western Cape was developed. The model of a typical farm was then used to develop a second hypothesised farm that had a mechanical system to recover waste i.e. the Lift-up dead fish and waste collector system. The third model farm was developed for a hypothesised farm using semi-intensive floating tank system (SIFTS) based on production information from results obtained on trials of the system carried out in Australia (Patridge et al., 2005) and adapted to rainbow trout production conditions in the Western Cape. The fourth hypothesised farm of an intergrated closed bag system was developed using production data from a full scale pilot farm built in Flekkerfjord (Bodvin et al., 1996) that was adapted to suit rainbow trout production conditions in the Western Cape. Models of typical small scale trout farms were described as follows:

1. Small scale net cage farm (Farm 1).
2. Small scale net cage farm with Lift-up dead fish and waste feed collector (Farm 2).
3. Small scale farm using a semi-intensive floating tank system (SIFTS) (Farm 3).
4. Small scale intergrated farm using closed bags (fish, mullet & macroalgae) (Farm 4).

The modelled farms compared differed on production techniques, feed management and waste recovery. In order to assess the effectiveness of the techniques in waste removal, nutrient and waste accumulation on the small scale farms was estimated using the mass balance models. Mass balance models were used to compare generation of waste at each farm as well as simulated waste recovery using the different techniques. Identification of methods from literature and collection of more information on the methods was important in this study because currently there are no techniques that are being used to recover waste in water based aquaculture systems in the Western Cape. Further discussions were done with people involved in aquaculture and farmers on suitability and applicability of the techniques.

### 4.3.2 Comparative financial analysis of the modelled small scale trout farms

A comparative financial analysis of the four modelled typical small scale trout farms using different production techniques was carried out. The costs (physical inputs used for the different production techniques) and benefits (the output produced from the use of the different techniques) of the alternative production techniques were obtained from questionnaires (personal interviews), Hands-On Fish Farmers Cooperative, Three Streams Smokehouse (involved in supply of fingerlings and buys fish from the farmers) and organisations that supply aquaculture equipment and machinery.

Multi-period budgets were prepared for the typical small scale trout farms using different production techniques. Benefits and costs were discounted to accommodate project effects occurring at different points in time. Comparison was done using the three discounting measures, namely the benefit cost ratio (BCR), net present value (NPV) and internal rate of return (IRR) (Gittinger, 1972). Cash flows were all in real terms (i.e. adjusted for inflation), with prices and costs assumed constant over the investment time period. In each case, NPV was calculated based on the expected benefits over a ten year period. The general rule that was used to choose the project life was the economic life time or the technical life time of the major investment asset that is cages (Gittinger, 1972). The opportunity cost of capital was represented by the discount rate and in this analysis 8 percent was used.
The decision rule for the NPV method was to accept all projects with a positive net present value as it implies that investment is financially worth since the return exceeds costs (Gittinger, 1972). In ranking the production techniques, the technique with the highest NPV was chosen first as the production technique with highest returns. The BCR ratio was also used to compare the production techniques. If the BCR was exactly equal to one, then production using that particular technique produced zero net benefits over its lifetime i.e. the discounted benefits just equalled discounted costs. In cases where the calculated BCR was less than one, then the production technique generated losses and if it was greater than one then the benefits of using the production technique outweighed the costs. In ranking the projects, the production technique with the highest benefit cost ratio was ranked first as it indicated highest returns on investment. IRR is that discount rate which makes the net present value of the cash flow equal to zero. Production techniques were accepted if IRR is greater than the cost of capital (interest rate) (Gittinger, 1972).

Sensitivity analysis was used to explore the effects of uncertainty in the key parameters of the production techniques. Uncertainty was likely to arise from changes in prices of inputs such as feed and fingerlings that were likely to increase. Prices of trout were also another uncertainty that was likely to change in future. Sensitivity analysis was used to identify critical levels of the parameters that were likely to change and it helped to at least come to a judgement about the magnitude of a change of the parameters (Whitmarsh et al., 2006).

### 4.4 Data collection from households using the contingent valuation method

Most of the benefits that arise from waste removal from aquaculture farms are environmental benefits that are not reflected in the comparative financial analysis that was carried out. All the production techniques generate significant environmental benefits and as such a contingent valuation method was used to estimate the environmental benefits not reflected in the financial analysis. A second questionnaire was designed and used to collect data from households to determine the economic value of good water quality in farm dams that were used for small scale trout farming. The household questionnaire designed was used to collect information on willingness to pay for improvement of water quality in dams that were used for aquaculture. The household questionnaire comprised of four sections (see Appendix 2). The first page had an introduction, purpose of study and a brief description of the hypothetical scenario. In Section A, information on household characteristics such as name, gender, age, marital status, income, size of household and education level of household heads was collected. In Section B, information on household income, income from aquaculture, fish consumption patterns and involvement of households in aquaculture was collected. In section C, questions on environmental issues were asked. In Section D, willingness to pay for water quality improvement was solicited for. A bidding card and pictures showing dams that had been affected by nutrient loading were also shown to respondents (see Appendix 3).

The valuation question in this study took the form of "willingness to pay" rather than "willingness to accept" because respondents tend to declare higher amounts if compensation is used (Mitchell & Carsons, 1989). The elicitation format used was the close ended approach. Haneman (1985) suggests that in a close ended approach, individuals responses will be more reliable if they are only required to place bounds on their willingness to pay. Cameron and James (1987) (cited in Hayes et al., 1992) also suggest that the "closed ended" (CVM) approach generates a scenario most similar to that encountered by consumers in their usual market transactions. A bidding card was designed and respondents were asked on the amount they were willing to pay from that card for different water quality change scenarios. The specific CVM question asked to the respondent was:

*"Let us say the dam on the farm is the only source of water on the farm and you use the water from the dam for domestic purposes, recreational fishing, swimming and the water is also used for irrigation and aquaculture. Due to accumulation of waste from different sources, algal blooms (unwanted plants) grow inside the dam. Water quality inside the dam change from its current state to a state shown in attached pictures (taken from certain dams in South Africa (see Appendix 3)). Considering that you use the water from the dam for the above mentioned uses, how much will you be willing to pay (contribute) annually towards putting in place measures that prevents water from the dam to change to a state similar to that shown on the picture and improve it to be suitable for mentioned uses"* (see Appendix 2).

Respondents were shown pictures of dams where water quality had been degraded due to nutrient loading. The bidding card was used together with pictures showing areas that have been affected by algal blooms due to nutrient loading (see Table 4.1). The bidding card showed different amounts of willingness to pay for water quality improvements to meet criteria for which the dam water is used for. Respondents were asked to value three water quality changes: (1) an improvement that allows water to be suitable for fish production and irrigation, (2) an improvement which allows safe swimming (acceptable for humans to be in contact with the water without any fear of any skin diseases), and (3) an improvement which allows safe use of water for domestic purposes (such as washing clothes, cleaning dishes and any other domestic use excluding drinking and cooking). Respondents were randomly assigned bid values from a list of seven bid values as indicated in the bid card in Table 4.1.

**Table 4.1: Bid card used to solicit for willingness to pay for water quality improvement**

| Water quality improvement scenarios | From state shown on the pictures to state suitable for Fish production and Irrigation | From state suitable for Fish production to Swimmable | Swimmable to a state suitable for domestic uses |
|---|---|---|---|
| **1** | **R15, R30, R40** | **R15, R30, R40** | **R15, R30, R40** |
| **2** | **R20, R40, R45** | **R20, R40, R50** | **R20, R40, R50** |
| **3** | **R25, R50, R60** | **R25, R50, R60** | **R25, R50, R60** |
| **4** | **R40, R60, R75** | **R60, R70, R80** | **R40, R60, R80** |
| **5** | **R60, R80, R90** | **R60, R80, R90** | **R60, R80, R90** |
| **6** | **R90, R100, R120** | **R90, R100, R120** | **R90, R100, R120** |
| **7** | **R130, R180, R200** | **R130, R180, R200** | **R130, R180, R200** |

The first bid value was the starting WTP bid for the first question. Right after the first question, the respondents were offered a second bid value that was higher than the first starting value if his/her answer to the first question was “yes”, if the first answer was “no” the respondent was offered a lower value. The ranges of the seven bid values were determined based on a pilot test and discussions with people involved in small scale aquaculture farming. Respondents were asked to state the maximum amount they were willing to pay each year for the improvements. The researcher included a follow up question on protest answers to ensure that respondents gave reasons why they were not willing to pay for water quality improvements. The maximum willingness to pay for improvement of water quality to suit the three categories were analysed using mean or median as suggested by Hanemann (1985) and Hayes et.al (1992).

In a CVM, the population should in principle be all the beneficiaries of the improvement in environmental amenity to be evaluated. In this survey, the scope of the population included all the people who directly or indirectly benefit from water from the irrigation dams. Household questionnaires were filled on the same ten farms where small scale trout farm questionnaires were filled in. The stratified random sampling method was used to choose respondents on each farm to ensure that key sub populations that were involved at differing levels in aquaculture farming were included in the sample. The population was divided into two sub frames. The first stratum included respondents who were involved in the aquaculture project and, second group comprised of respondents who were not directly involved in aquaculture farming. The division of the population was based on the different levels of understanding of aquaculture activities by respondents on the farm. On each farm six questionnaires were to be filled in, three for each sub frame. Respondents were chosen randomly for each stratum based on availability and willingness to participate in the survey.

A decision was made to carry out interviews in person so as to reduce the problems of low response and incomplete questionnaires that is usually associated with other methods of carrying out surveys. The researcher was assisted by the assistant technical manager of the Hands-On Fish Farmers Cooperative in instances where respondents could not understand English and used Afrikaans. 51 questionnaires were successfully filled in through personal interviews in June 2010 on the 10 farms visited in Worcester, Botrivier, Wolseley, Franschhoek, Paarl and Stellenbosch where there were small scale trout farming activities in irrigation dams. Nine questionnaires were not successfully completed as the respondent indicated that they did not have all the information requested half way through the interview and were not included in the analysis. The response rate in the study was 85 percent of successfully completed questionnaires. Use of personal interviews to fill in the questionnaire helped in explaining and understanding of the scenario by respondents and this reduced the effects of biases that are usually associated with surveys. In designing the questionnaire a decision was made on the payment method to be used and a once-off annual payment was used as the payment method. In explaining the form of payment to be used, the researcher reminded the respondents of the sacrifices they were making as well as their budget constraints to ensure that respondents gave rational answers.

## 4.5 Data Analysis

### 4.5.1 Descriptive statistics

A data sheet with all the variables of data collected was prepared in Excel. The statistics were calculated using STATISTICA computer program. Histograms were used to present descriptive statistical data in order to see the nature of the distribution of the particular variables and to be able to identify possible outliers. Alternatively, frequency tables were also used to present the data. Although histograms and frequency tables show the same information, it is easier to identify outliers in histograms. This is why in most cases histograms are used to present data (StatSoft Inc., 2008).

### 4.5.2 Statistical inferential analysis

- **Comparing a continuous variable to a nominal (categorical) variable**

Continous variable is data that can take a wide range of values e.g. age, size of household and income whereas nominal variables indicate categories into which the respondents may fall into, for example gender (StatSoft Inc., 2008). In order to test whether a continuous variable differed over the different categories of a nominal variable, analysis of variance was used (ANOVA). In comparing continuous variables (for example age of respondent) versus nominal variables (like involvement in aquaculture), ANOVA was used to investigate if the means of the continuous variables (age) differed between the levels of the nominal variable (those who are involved in aquaculture and those who are not involved).

The means of the continuous variables differed significantly if the p-values were found to be less than α=0.05 (α=0.05 is the significance level of the test). The ANOVA F-test was used when data was normally distributed and in cases where data was not normally distributed, non-parametric tests specifically Mann-Whitney tests were used. To verify if the data was normally distributed, the graph of normal probability plots of the residuals was checked and if the plots were very close to the red line, it indicated that the data for each group was indeed normally distributed and the ANOVA F-test was appropriate. The Mann-Whitney test was used for data that was not normally distributed. A p-value of less than α=0.05 also indicated that the means of the continuous variables differed significantly between the levels of the nominal variables.

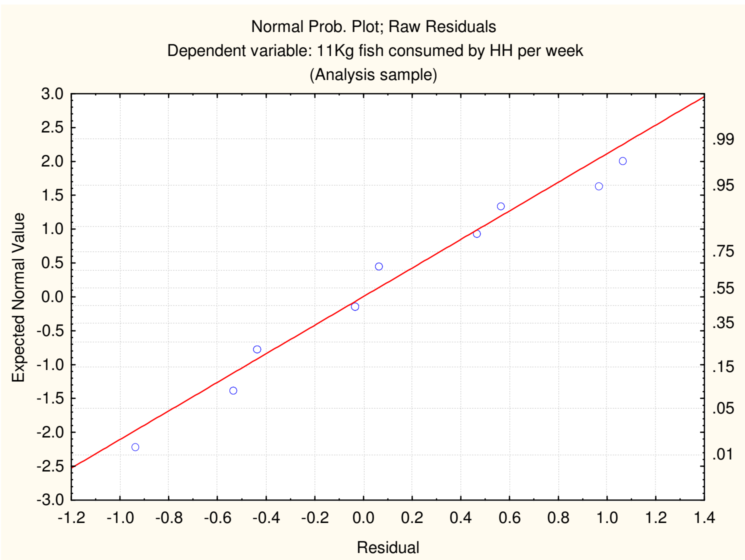



**Figure 4.1: Normal probability plots of the residuals for fish consumption by households per week**

Figure 4.1 shows the amount of fish consumed by households per week normality test example observed in the analysis. It shows that the amount of fish consumed by household per week was not normally distributed because the dots deviate quite a lot from the red line, so the researcher did not make the assumption that amount of fish consumed by households per week was normally distributed, and consequently in this case the Mann-Whitney test was more appropriate.

- **Comparing a nominal variable against another nominal variable**

In cases where a nominal variable was compared to another nominal variable, contingency tables (commonly known as a cross-tabulation) were used. The assumption was that the levels of the one nominal variable do not influence the levels of the other nominal variable, i.e. two variables are independent. The method tested the influence of one nominal variable on the other, and tested whether it was sufficient to state that the two variables were not independent. This was done by using an appropriate chi-square test i.e. the Pearson's chi-square or alternatively the more robust maximum-likelihood (ML) chi-square test could have been used.

- **Comparing a continuous variable against another continuous variable**

In comparing a continuous versus another continuous variable, regression or correlation analysis was used. The independent variable X was chosen as the variable over which the researcher could observe with lesser variance than the other variable Y which is called the dependent variable. The researcher determined wheher the influence of the independent variable X on the dependent variable Y was significant or not.

## 4.6 Summary

This chapter outlined the methods that were used to gather data used to answer the research questions. Secondary data was collected from various organisations that are involved in aquaculture and primary data was collected from small scale trout farms and households using questionnaires. Primary data collected using the small scale trout farm questionnaire was used to develop model typical small scale farms that use identified production techniques to produce trout. Data collected from households was analysed using STATISTICA where descriptive and inferential methods were used to analyse and present the data.

# CHAPTER 5

# ANALYSIS OF SMALL SCALE RAINBOW TROUT FARM RESULTS AND DISCUSSIONS

## 5.1 Introduction

The previous chapters revealed that waste and dissolved nutrients added from aquaculture farms has a potential of affecting uses of water if released above certain limits. It was also noted that the regulatory framework of aquaculture in South Africa requires that aquaculture farmers move towards adoption of techniques that minimise environmental impacts. In this chapter, results of the small scale rainbow trout farms survey will be presented. Characteristics of small scale rainbow trout farms in the Western Cape will be presented. Models of small scale farms using identified production techniques to remove waste will be described. Results of the mass balance analysis will be presented. Results of comparison of financial implications of the alternative production techniques to small scale rainbow trout farming will be discussed.

## 5.2 Description of small scale rainbow trout farms

Ninety percent of the small scale aquaculture farms visited were located on agricultural farms, where aquaculture farmers produce rainbow trout in privately owned farm dams. One small scale aquaculture farm in Worcester uses a municipal dam to farm rainbow. The main use of water from the dams that are being used for small scale aquaculture farming is for irrigation purposes. On agricultural farms, water is used for irrigating wine grapes and fruit trees while for the municipal dam, water is mainly used for irrigation of a golf course nearby. Water from the dams is sometimes used for recreational fishing and domestic purposes. Nine small scale aquaculture farms are operated by full time employees on the agricultural farms and they work on the aquaculture farms part time. For the small scale aquaculture farm on a municipal dam, the farm is operated by three Worcester residents. Operation of small scale aquaculture farms on privately owned dams in the Western Cape is based on agreements between the farmer and the farm workers on promise of good management practice and maintenance of good water quality in the dams.

The number of farm workers operating a small scale rainbow trout farms at each agricultural farm differs and range from 3 to 25 people. It was noted that all people involved in small scale rainbow trout farming received on site training and attended workshops organised by the University of Stellenbosch. Mentorship and in-house training is also offered to the small scale trout farmers through the Hands-On Fish Farmers' Cooperative. On all the small scale trout farms, fish farming is a secondary activity for the farm workers and their participation in fish production is set up in such a way that their activities do not interfere with their full time employment on the agricultural farm. Group members take turns to feed the fish and feeding is carried out before work, during lunch and after work. Eighty percent of the small scale aquaculture farmers indicated that they required further training especially in financial management. Other areas of further training mentioned by farmers include cage building and maintenance.

### 5.2.1 Location of small scale aquaculture farms

All the small scale rainbow trout farms are located within a radius of 25 km from nearest small towns (Stellenbosch, Worcester, Franschoek, Botrivier, Paarl, Wolseley) and the furthest distance of small scale aquaculture farm from nearest small town observed was 25 km for Mountainvinyards (Bochendal) from Paarl (nearest town). Location of dams on the agricultural farms was also investigated. Five of the dams used for aquaculture were located within a river system, while on four dams water is channelled from a bigger dam and one dam is an estuary. Location of the dams is important as it determines the potential effects of waste from aquaculture farms on the environment. In dams that are located within a river system, there are chances that waste from aquaculture farms is occassionally re-suspended and flushed out during flooding thereby removing waste from the dam. Sixty percent of the farms had been in operation for a period of between 1 to 5 years, thirty percent for a period of between 6 to 10 years with only one farm falling in the 11 to 15 years category. Worcestor Forel aquaculture project in Worcester has been operational for the longest period.

### 5.2.2 Production on the small scale farms

All the small scale aquaculture farms are using net cage production technique to farm rainbow trout in monoculture (producing one fish species in the net cages). Net cages are stocked with rainbow trout fingerlings weighing between 150g to 200g in early May. Rainbow trout are fed with a ration of commercial pelleted feed for six months until they reach a marketable size at all the farms. Stocking rates (2009 fish production season) used at the small scale farms ranged from 0.708 $kg/m^3$ to 1.76 $kg/m^3$ and on average the stocking rate was 1.55 $kg/m^3$. Harvesting of fish is done in October when the fish are weighing between 1.1 kg to 1.3 kg. All the small scale aquaculture farms were operating at full capacity and 80 percent of the farms have been operational since they were established. Two farms indicated that they had to stop production during one of the fish farming season but it was mainly due to shortages of fingerlings in that season (a problem that have since been rectified).

The small scale farms are only involved in growing out of rainbow trout and they acquire fingerlings from hatcheries around the Western Cape. For the 2009 season, the visited small scale rainbow trout farms produced between 6 to 10 tonnes of trout with an average of 6.38 tonnes produced at each small scale farm. Production on all the small scale farms is for commercial purposes. The small scale rainbow trout farmers supply their A grade fish (weighing 900g and more) to Three Stream Smokehouse for processing and fish that fails to meet the required grade (weighing less than 900g) for processing is supplied to supermarkets where it is sold as fresh fish. In the 2009 season, 70 to 90 percent of fish produced from the small scale trout farms were of grades accepted by Three Streams Smokehouse for processing (weighing 900g and more).

### 5.2.3 Operational structure

All the small scale farms visited were members of the Hands-On Fish Farmers Cooperative. They operate under a private–public partnership business model presented in Figure 5.1. The operational model is an active partnership between black entrepreneurs, banking institution and an established fish processing company. The Hands-On Fish Farmers' Cooperative is helped on the supply side by the Division of Aquaculture of the University of Stellenbosch (see Figure 5.1). The cooperative also works closely with hatcheries in Jonkershoek, Reegmoight and Franschoek to supply fingerlings to the farmers. The financial and administrative part of the cooperative is handled by the New Development Company and the technical side of the management, research and extension services is carried out by the Division of Aquaculture of the University of Stellenbosch through the technical manager of the cooperative.

The Hands-On Fish Farmers' Cooperative obtains loans from banking institutions on behalf of the farmers and it provides the farmers with all the required production inputs and costs to meet the day to day running of the aquaculture projects. Farmers produce under contract from the Hands-On Fish Farmers Cooperative. A processing company by the name Three Streams Smokehouse buys fish from the small scale farmers. The operational model reduces financial, input and marketing risk for the small scale farmers and leaves the farmer with the responsibility of managing production risk. Mentorship and extension services provided by the Hands-On Fish Farmers Cooperative further helps small scale farmers to cope with production risk through reducing production losses due to disease outbreak, feed shortages, and fish escapees

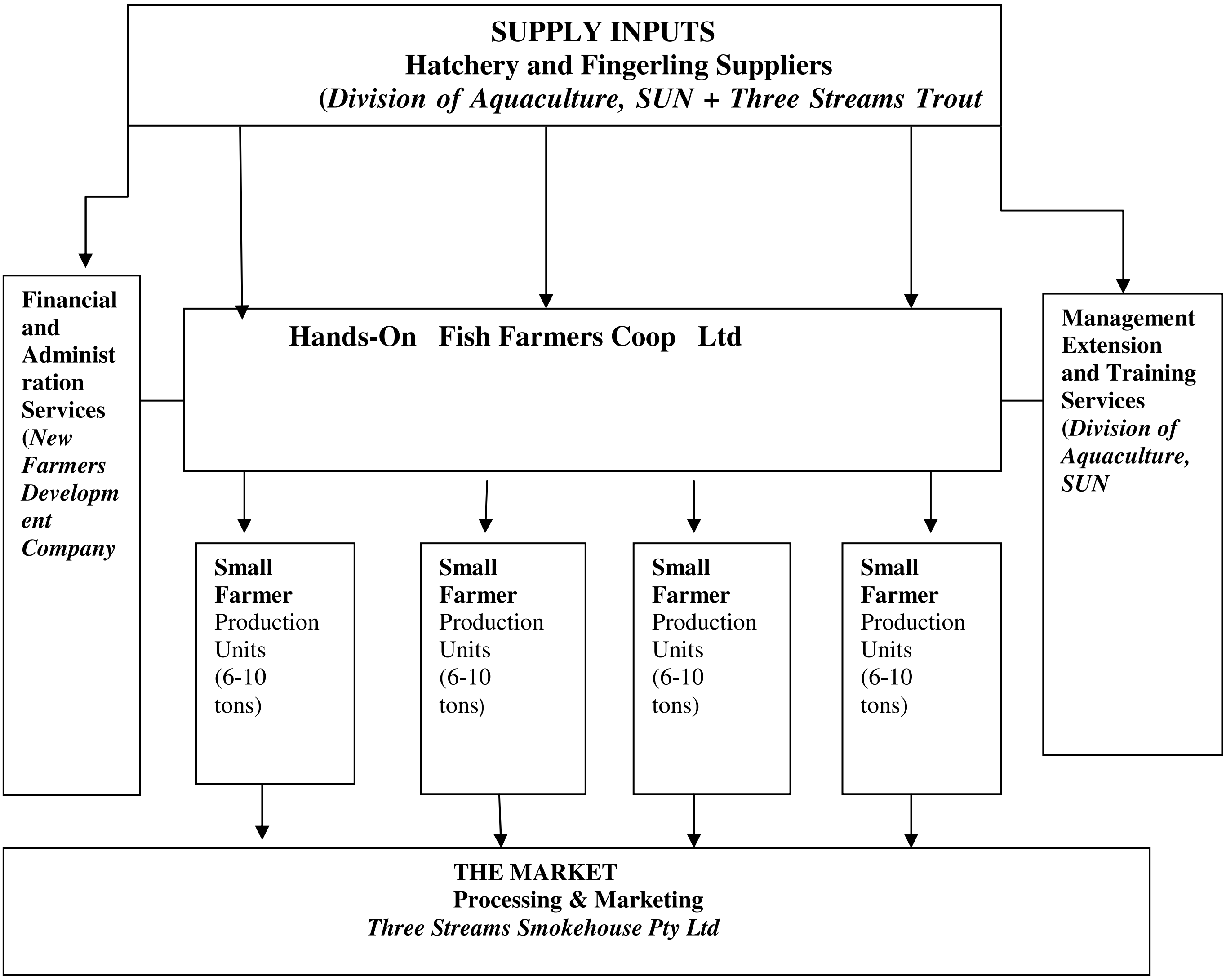



**Figure 5.1: Operational model of small scale trout farming projects in the Western Cape**

Source: Botes et al. (2006)

### 5.2.4 Rating on effectiveness of production techniques

Farmers were shown pictures of alternative production techniques that they could use to recover waste from aquaculture. The production techniques were explained to farmers and they were asked to rate their perceived effectiveness of the production techniques on a scale of one to ten. If they gave a rating of five or above, indicated that the farmer regarded the technique as effective and a rating of less than five meant that the technique is perceived as not effective. For the Lift-up technique, 60 percent of the aquaculture farmers gave the production technique a rating of five and above indicating that they rated the technique as effective in removing waste. Forty percent of the small scale farmers were of the opinion that the technique was not effective and gave a rating of less than five. The same ratings were also given for the intergrated production technique with six farmers giving the technique a rating of five or more and four rating the technique as not effective.

For the SIFTS technique, 70 percent of the farmers rated the technique as being effective and 30 percent rated the technique as not effective.

### 5.2.5 Environmetal issues in small scale aquaculture farming

Small scale rainbow trout farmers were further asked to rate the importance of a number of environmental issues in their operations and their ratings are presented in Table 5.1.

**Table 5.1: Rating on importance of environmental issues to operation of small scale aquaculture farms**

| Environmental issue | Not important (1) | Little importance (2) | Neutral (3) | Some importance (4) | High importance (5) | Total responses |
|---|---|---|---|---|---|---|
| Site selection | 0 | 0 | 1 | 2 | 7 | 10 |
| Water quality | 0 | 0 | 0 | 2 | 8 | 10 |
| Water pollution | 0 | 0 | 1 | 2 | 7 | 10 |
| Impact of species on environment | 0 | 2 | 4 | 3 | 1 | 10 |
| Feed management | 0 | 0 | 1 | 3 | 6 | 10 |
| Chemical use | 1 | 1 | 4 | 4 | 0 | 10 |
| Disease management | 0 | 1 | 2 | 5 | 2 | 10 |

Rating: 1= no importance 2= little importance 3=neutral 4= some importance 5=high importance

Seventy percent of farmers gave site selection a rating of five indicating that site selection is of “high importance” in setting up small scale rainbow trout farms. They indicated that a thorough assessment was carried out to determine the potential impacts of aquaculture on the dam system before setting up the aquaculture farms. Maleri (2007) also mentioned site selection as an important factor in small scale fish farming in irrigation dams in the Western Cape. The Hands-On Fish Farmers’ Cooperative and Division of Aquaculture of the University of Stellenbosch assisted small scale aquaculture farmers on assessing whether dams identified by the farmers were suitable for setting up small scale farms.

When aquaculture farmers were asked to rate the importance of good water quality in dams, 80 percent indicated that water quality was of “high importance” in aquaculture. Twenty percent of the farmers gave a rating of four showing that water quality was of “some importance” in aquaculture (see Table 5.1). They also pointed out that controlling water pollution is very important to their operations with 70 percent indicating that water pollution was of ‘high importance” while 20 percent indicating it was of “some importance”, 10 percent were neutral (see Table 5.1). Other environmental issues that small scale aquaculture farmers rated as of “high importance” include feed management that was given a rating of five by 60 percent of the farmers. Twenty percent gave a rating of five for disease management indicating that it is of “high importance”.

## 5.3 Description of modelled typical small scale rainbow trout farms

### 5.3.1 Farm 1: Small scale net cage farm

Modelled Farm 1 is a typical small scale rainbow trout farm in the Western Cape that uses net cages that are $1000m^3$ in volume. On the modelled farm, fingerlings weighing an average of 150g are put into the cages at a stocking rate of 1.55 $kg/m^3$ to produce 8.2 tonnes of fish per year. The fish are grown in water and fed a percentage of their weight twice everyday for six months from May to October and harvested at an average weight of 1.2 kg. Survival rate of the fish is 85 percent and stocking density at harvesting is 8.2 $kg/m^3$. Food conversion rates (FCR) of between 1.23 and 2.5 were reported for rainbow trout fed commercial feed in a number of studies (Hall et al., 1992; Warren-Hansen, 1982a; Sumari, 1982 all cited in Islam, 2005; Foy & Rosell, 1991). In this study, a food conversion rate (FCR) of 1.5 was used for the modelled small scale trout farm (average FCR of small scale net cage rainbow trout farms visited for 2009 season in Western Cape). Rainbow trout feed from Aquanutro containing 6 percent nitrogen and phosphorus 1.27 percent is used by the trout farmers. On Farm 1, there is no waste recovery and this farm is to be compared with three other farms where there is waste recovery in the cost benefit analysis. An assumption was made for this farm that production has to be reduced by 10 percent after 5 years due to accumulation of waste.

### 5.3.2 Farm 2: Small scale farm with a Lift-up dead fish and feed waste collector

Farm 2, is a modelled small scale net cage farm fitted with a Lift-up dead fish and waste feed collector. The total volume of the net cages is $1000m^3$. On the modelled farm, fingerlings weighing an average of 150g are put into the cages at a stocking rate of 1.69 $kg/m^3$ to produce 9.96 tonnes of fish. The fish are grown in water and fed a percentage of their weight twice everyday for six months from May and harvested in October at an average weight of 1.2 kg. The survival rate of the fish is 85 percent and stocking density at harvesting is 9.96 $kg/m^3$. On this farm, waste is recovered and this enables the farmer to use a higher stocking rate. The additional feature of this model farm is re-using of the collected waste. Composting is an effective way of transforming waste recovered from aquaculture farms into valuable products as compost can be used as a fertiliser in vegetable production. Partridge et al. (2005) also suggested use of waste from aquaculture for generation of methane gas. If waste is converted to valuable products, the cost of recovering waste are outweighed by the benefits that will arise from better water quality for fish production and extra income from compost.

### 5.3.3 Farm 3: Small scale farm using Semi-Intensive Floating Tank System

In this study, a modelled small scale trout farm using Semi-Intensive Floating Tank System (SIFTS) of volume $1000m^3$ was proposed. Fingerlings weighing an average of 150g are put into the tanks at a stocking rate of 6.34 $kg/m^3$ with 85 percent survival rate and stocking density at harvesting of 40 $kg/m^3$. The fish are grown in water and fed a percentage of their weight twice everyday for six months from May to October and harvested at an average weight of 1.2 kg. The food conversion rate (FCR) of 0.97 attained for the trial of the system was used in this study. The low FCR attained for this production technique for rainbow trout is at the lower end of the optimum range reported for the species (1.23-2.5) and is attributed to the ability to minimise food wastage by using the solid waste collector to gauge when satiation is reached during feeding the trout (Partridge et al., 2005). Quick removal of waste in this production technique enables the farmer to use high stocking rates compared to Farm 1 where there is no waste recovery. The system recovers 90 percent of particulate waste (Partridge et al., 2005), based on the assumption that 25 percent of nitrogen and 75 percent of phosphorus lost from aquaculture farms appear in particulate form (Ghosh, 2000).

### 5.3.4 Farm 4: Small scale intergrated farm using floating closed bags

Farm 4 is a theoretical model of an intergrated small scale aquaculture farm using floating closed bags (alternatively nets can be used in place of bags to confine fish inside cages). The hypothesised farm in this study is based on production data from a full scale pilot study farm built in Flekkefjord as described by Bodvin et al. (1996) and Ghosh (2000). A theoretical fresh water farm comprising of four trout fish units with a total production volume of $2000m^3$ linked to four mullet units each with a volume of $500m^3$ and pumping capacity of $5.5m^3$/minute is proposed. The modelled trout unit is stocked with fingerlings weighing 150g at a stocking rate of 3.7 $kg/m^3$ with 85 percent survival rate and stocking density at harvesting of 16 $kg/m^3$ for the farm. The fish are grown in water and fed a percentage of their weight with commercial feed twice everyday using demand feeders for six months from May and harvested in October at an average weight of 1.2 kg. Water from the fish unit containing particulate and dissolved nutrients is pumped into four mullet units using an airlift pumps. The mullet unit is assumed to convert 25 percent of particulate nitrogen and phosphorus emissions.

Dissolved nutrients from the trout and mullet units are then pumped into a macroalgae or floating vegetable unit. The macroalgae unit can be placed outside the dam where hydroponics can be used to grow vegetables and the water is then returned back into the dam after passing through the vegetable unit. Alternatively, macroalgae or vegetables can be grown in cages during summer months to absorb dissolved nutrients that would have been produced during the winter season when trout is grown. Mullet unit and macroalgae (or vegetable) production units are then modelled based on total utilisation of dissolved nutrients and it is assumed that 225 tonnes of mullet are produced and 846 metric tonnes of macroalgae (or vegetables) are produced every year. Income from the rainbow trout unit is considered for comparison in this study although the mullet and macroalgae (or vegetables) produced is also of economic value. The water coming of the whole system is assumed to be waste free. The costs and benefits of such a system were estimated using local production costs.

Note: that the proposed figures are only for this comparative economic analysis and are not based on any biological research done for use of the system in South Africa.

### 5.3.5 Production plans for the modelled small scale farms

The farm production plans of the modelled small scale rainbow trout farms using different production techniques described in section 5.3.1 to 5.3.4 are summarised in Table 5.2. The initial weight of fingerlings stocked on the farms is the same and it reflects the average weight of fingerlings stocked in small scale rainbow trout farms in the Western Cape. However, stocking rates on the small scale trout farms differs because, on farms where there is recovery of waste, farmers can use higher stocking rates without facing problems related to water quality caused by waste accumulation.

**Table 5.2: Farm production data for four modelled small scale farms using different production techniques**

| Item | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| Volume of cage ($m^3$) | 1000 | 1000 | 1000 | 2000 |
| Initial weight of fish (g) | 150 | 150 | 150 | 150 |
| Stocking rate ($kg/m^3$) | 1.55 | 1.69 | 6.34 | 3.7 |
| Days in water | 180 | 180 | 180 | 180 |
| Mortality (%) | 15 | 15 | 15 | 15 |
| Average weight @ harvest (kg) | 1.2 | 1.2 | 1.2 | 1.2 |
| Density @ harvesting ($kg/m^3$) | 8.2 | 9.96 | 40 | 16 |
| Harvest (kg) | 8200 | 9960 | 40000 | 32000 |
| Feed used | 13200 | 14940 | 38800 | 64500 |
| FCR | 1.5 | 1.5 | 0.97 | 1.5 |
| Feeding technique | Hand feeding | Hand feeding | Hand feeding | Demand feeder |
| Feed wastage (%) | 20 | 20 | 20 | 20 |

Note: Production data for modelled Farm 3 (SIFTS) and Farm 4 (integrated system) were worked out based on production data in countries where the production techniques are used and adjusted to suit local production conditions.

At all the modelled farms, rainbow trout are fed a commercial feed twice a day for 180 days until they grow to a size of between 1.1kg to 1.3kg. Food conversion rate (FCR) is lower on Farm 3 because the production technique ensures better feed management as feeding stops as soon as satiation is attained for the fish.

## 5.4 Estimation of nutrient loading for the modelled small scale farms

### 5.4.1 Farm 1: Small scale net cage farm

On a typical small scale net cage farm (Farm 1), expected nutrient loading into the environment based on the mass balance model is as indicated in Tables 5.3, 5.4 and 5.5. For every tonne of rainbow trout produced using feed that contains 6 percent nitrogen and 1.27 percent phosphorus with FCR of 1.5, 60 kg of nitrogen are added into the environment (see Table 5.3). On a typical small scale farm that produces 8.2 tonnes of fish, 492 kg of nitrogen in dissolved and particulate form is lost to the environment. The estimated figures indicate that a small scale net cage farm can add a significant amount of nitrogen into dam water that can change the dam ecosystem.

**Table 5.3: Mass balance model showing nitrogen loading on a modelled typical small scale net cage aquaculture farm per tonne of rainbow trout produced (Farm 1)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AXB | 1500 |
| 4 | Feed wastage (%) | Dw | 10 |
| 5 | Feed waste(kg) | D=CXDw/100 | 150 |
| 6 | Feed consumed (%) | E=C(100-Dw)/100 | 1350 |
| 7 | Feed undigested (%) | F | 20 |
| 8 | Feacal production (kg) | G=EXF/100 | 270 |
| 9 | Nitrogen content of feed (%) | H | 6 |
| 10 | Nitrogen content of feaces (%) | I | 4 |
| 11 | Nitrogen in feed supply (kg) | J=CXH/100 | 90 |
| 12 | Nitrogen in feed waste (kg) | K=DXH/100 | 9 |
| 13 | Nitrogen ingested (kg) | L=EXH/100 | 81 |
| 14 | Nitrogen retained in fish @ 3% (kg) | M=Ax3/100 | 30 |
| 15 | Total nitrogen excreted (kg) | N=L-M | 51 |
| 16 | Nitrogen in feaces (kg) | O=GX I/100 | 10.8 |
| 17 | Nitrogen in catabolic product (kg) | P=N-O | 40.2 |
| 18 | Total nitrogen load (kg) | Q=K+O+P | 60 |
| 19 | Recovery of nitrogen load if any (kg) | R | 0 |
| **20** | **Net nitrogen load on environment (kg)** | **S=Q-R** | **60** |

Phosphorus added into the environment was calculated using the mass balance model as presented in Table 5.4. A small scale net cage farm adds 14.25kg of phosphorus for every tonne of rainbow trout produced. On a typical small small scale that produced 8.2 tonnes of fish annually, the total amount of phosphorus added into the dam water is 116.85kg in both particulate and dissolved form. A significant amount of phosphorus is added into the dam water and this should be of concern to the small scale aquaculture farmer. Phosphorus is the most important factor that farmers should pay attention to as its concentration in a fresh water body results in eutrophication (Gumisiriza, 2009; Pillay, 2004). It causes rapid growth of algae that directly or indirectly affect fish production and use of water for irrigation purposes. Table 5.4 show that 8.295kg of phosphorus is added into the environment in dissolved form and 5.955 kg is added in particulate form for every tonne of rainbow trout produced. It also indicates that only 0.48 percent of phosphorus that is added into the system is retained in fish.

**Table 5.4: Mass balance model showing phosphorus loading on a modelled typical small scale net cage farm per tonne of rainbow trout produced (Farm 1)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AXB | 1500 |
| 4 | Feed wastage (%) | Dw | 10 |
| 5 | Feed waste (kg) | D=CXDw/100 | 150 |
| 6 | Feed consumed (%) | E=C(100-Dw)/100 | 1350 |
| 7 | Feed undigested (%) | F | 20 |
| 8 | Feacal production (kg) | G=EXF/100 | 270 |
| 9 | Phosphorus content of feed (%) | H | 1.27 |
| 10 | Phosphorus content of feaces (%) | I | 1.5 |
| 11 | Phosphorus in feed supply (kg) | J=CXH/100 | 19.05 |
| 12 | Phosphorus in feed waste (kg) | K=DXH/100 | 1.905 |
| 13 | Phosphorus ingested (kg) | L=EXH/100 | 17.145 |
| 14 | Phosphorus retained in fish @ 0.48% (kg) | M=Ax0.48/100 | 4.8 |
| 15 | Total phosphorus excreted (kg) | N=L-M | 12.345 |
| 16 | Phosphorus in feaces (kg) | O=GX I/100 | 4.05 |
| 17 | Phosphorus in catabolic product (kg) | P=N-O | 8.295 |
| 18 | Total phosphorus load (kg) | Q=K+O+P | 14.25 |
| 19 | Recovery of phosphorus load if any (kg) | R | 0 |
| **20** | **Net Phosphorus load on environment (kg)** | **S=Q-R** | **14.25** |

The amount of phosphorus lost into the environment as part of uneaten feed is 1.905 kg for every tonne of rainbow trout produced (see Table 5.4). If farmers improve feed management and reduce the amount of feed lost as uneaten feed they can significantly reduce the amount of phosphorus lost into the environment as part of uneaten feed. Fish also retains a small percentage of phosphorus applied as feed and if phosphorus component of feed is reduced to suit the dietary requirements of fish, then the amount of phosphorus lost to the environment can also be reduced. Table 5.5 below shows the amount of solids that accumulates beneath a cage farm for every tonnes of fish produced.

**Table 5.5: Mass balance model showing total solids loading on a modelled small scale net cage farm per tonne of rainbow trout produced (Farm 1)**

| S.I No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Unconsumed feed (kg) | D=CXDw/100 | 150 |
| 2 | Feacal production (kg) | G=EXF/100 | 270 |
| 3 | Total solid load (kg) | H=D+G | 420 |
| 4 | Recovery of solid if any | R | 0 |
| **5** | **Net solid on environment (kg)** | **S=H-R** | **420** |

On a typical small scale net cage farm, 420kg of solids is added into the environment for every tonne of rainbow trout produced (see Table 5.5). The total solids lost into the environment are a combination of uneaten feed and metabolic excretes (feaces). The mass balance models estimate that a typical small scale net cage farm releases 60kg's of nitrogen (see Table 5.3), 14.25kg of phosphorus (see Table 5.4) and 420kg (see Table 5.5) of total solids into the environment for every tonne of rainbow trout produced. Foy and Rosell (1991) reported 76 kg and 18 kg of nitrogen and phosphorus respectively to be lost to the environment for rainbow trout with FCR 1.83. Hall et al. (1990) also reported nutrients added to the environment as 80 kg of nitrogen and 16.6 kg of phosphorus. The difference in nitrogen and phosphorus loading from this study and literature can be attributed to feed composition and quality. There have been significant improvements in feed nutrient composition as manufacturers have managed to reduce nitrogen and phosphorus content of feed to match the dietary requirements of fish. An improvement in quality of feed with production of slow sinking feed with better stability in water has helped reduce emissions from aquaculture (Beirgheim & Forsberg, 1993; Tarcon & Foster, 2003). The estimations using the mass balance equation in this regard are close to the actual nutrient loadings to the environment.

### 5.4.2 Farm 2: Small scale net cage farm with a Lift-up system

On the hypothesised net cage farm fitted with a Lift-up dead fish and waste collector system, 48 kg's of nitrogen is lost into the environment (see Table 5.6). The Lift-up system fitted to the net cages recovers 80 percent of particulate waste released from the aquaculture farm. Table 5.6 show that the system recovers 12 kg of nitrogen for every tonne of rainbow trout produced. The total amount of nitrogen recovered on a typical small scale farm producing 9.96 tonnes of rainbow trout will add up to 119.52 kg of particulate nitrogen recovered from dam annually. The results indicate that the system recovers a significant amount of particulate nitrogen. The system recovers most of the particulate nitrogen with only 3 kg particulate nitrogen added into the environment. However, the system does not recover dissolved nitrogen resulting in 45 kg's of dissolved nitrogen being added into the environment. The results in Table 5.6 also indicate that in order to reduce nutrient loading on small scale trout farms, mechanical methods of waste recovery need to be combined with good feed management practices. Small scale farmers should strive to lower the feed conversion rate towards one as well as reduce feed wastage.

**Table 5.6: Mass balance model showing nitrogen loading on a modelled small scale net cage farm with a Lift-up system per tonne of rainbow trout produced (Farm 2)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AxB | 1500 |
| 4 | Apparent feed wastage (%) | Da | 10 |
| 5 | Recovery of feed @ 80% | Rf=CxDa/100x80/100 | 120 |
| 6 | Net feed wastage (kg) | D=(CxDa)-Rf | 30 |
| 7 | Net feed wastage as a percentage | Dw=(D/C)x100 | 2 |
| 8 | Feed consumed (%) | E=C(100-Dw)/100 | 1470 |
| 9 | Feed undigested (%) | F | 20 |
| 10 | Feacal production (kg) | G=ExF/100 | 294 |
| 11 | Nitrogen content of feed (%) | H | 6 |
| 12 | Nitrogen content of feaces (%) | I | 4 |
| 13 | Nitrogen in feed supply (kg) | J=CxH/100 | 90 |
| 14 | Nitrogen in feed waste (kg) | K=DxH/100 | 1.8 |
| 15 | Nitrogen ingested (kg) | L=ExH/100 | 88.2 |
| 16 | Nitrogen retained in fish @ 3% (kg) | M=Ax3/100 | 30 |
| 17 | Total nitrogen excreted (kg) | N=L-M | 58.2 |
| 18 | Nitrogen in feaces (kg) | O=Gx I/100 | 11.76 |
| 19 | Nitrogen in catabolic product (kg) | P=N-O | 46.44 |
| 20 | Total nitrogen load (kg) | Q=K+O+P | 60 |
| 21 | Particulate nitrogen load (@25%) (kg) | Pn=Qx25/100 | 15 |
| 22 | Recovery of particulate nitrogen (@80%) (kg) | Rn=Pnx80/100 | 12 |
| 23 | Net particulate nitrogen load on environment (kg) | Sn=Pn-Rn | 3 |
| 24 | Dissolved nitrogen load(@ 75% (kg) | Dn=Qx75/100 | 45 |
| **25** | **Total nitrogen load (kg)** | **Tn=Sn+Dn** | **48** |

Table 5.7 show the amount of phosphorus added into the environment from a net cage farm fitted with a Lift-up system. The system recovers a significant amount of particulate phosphorus with only 2.1 kg of particulate phosphorus added into the environment (see Table 5.7). Total phosphorus lost into the environment is 12.85kg for every tonne of rainbow trout produced. On a small scale farm producing 9.96 tonnes annually, the total amount of particulate phosphorus lost to the environment is 20.96 kg.

**Table 5.7: Mass balance model showing phosphorus (P) loading on a modelled small scale net cage farm with a Lift-up system per tonne of rainbow trout produced (Farm 2)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AxB | 1500 |
| 4 | Apparent feed wastage (%) | Da | 10 |
| 5 | Recovery of feed@ 80% | Rf=CxDa/100x80/100 | 120 |
| 6 | Net feed waste (kg) | D=CXDa/100-Rf | 30 |
| 7 | Net feed wastage as a percentage | Dw=(D/C)x100 | 2 |
| 8 | Feed consumed (%) | E=C(100-Dw)/100 | 1470 |
| 9 | Feed undigested (%) | F | 20 |
| 10 | Feacal production (kg) | G=ExF/100 | 294 |
| 11 | Phosphorus content of feed (%) | H | 1.27 |
| 12 | Phosphorus content of feaces (%) | I | 1.5 |
| 13 | Phosphorus in feed supply (kg) | J=CxH/100 | 19.05 |
| 14 | Phosphorus in feed waste (kg) | K=DxH/100 | 0.381 |
| 15 | Phosphorus ingested (kg) | L=ExH/100 | 18.669 |
| 16 | Phosphorus retained in fish @ 0.48% (kg) | M=Ax0.48/100 | 4.8 |
| 17 | Total phosphorus excreted (kg) | N=L-M | 13.869 |
| 18 | Phosphorus in feaces (kg) | O=Gx I/100 | 4.41 |
| 19 | Phosphorus in catabolic Product (kg) | P=N-O | 9.459 |
| 20 | Total phosphorus load (kg) | Q=K+O+P | 14.25 |
| 21 | Particulate load @ 75% (kg) | Pp=Qx75/100 | 10.6875 |
| 22 | Recovery of phosphorus @ 80% (kg) | Rp=Ppx 80/100 | 8.55 |
| 23 | Net phosphorus load on environment (kg) | S=Q-R | 5.7 |
| 24 | Net particulate 'P' load on environment (kg) | Sp=Pp-Rp | 2.1375 |
| 25 | Dissolved 'P' load(@ 75% (kg) | Dp=Qx75/100 | 10.6875 |
| **26** | **Total phosphorus load (kg)** | **Tp=Sp+Dp** | 12.825 |

For a small scale net cage aquaculture farm fitted with a Lift-up system, the net solid load to the environment is 35 kg for every tonne of trout produced (see Table 5.8). Nitrogen and phosphorus released into the environment in particulate form is 3kg and 2.14 kg respectively (see Table 5.8). There is a reduction of 385 kg of total solids loading into the environment. In addition, particulate nitrogen and phosphorus lost into the environment is reduced by 57 kg and 13 kg respectively for every tonne of rainbow trout produced.

**Table 5.8: Mass balance model showing total solids on a modelled small scale net cage farm with a Lift-up system per tonne of rainbow trout produced (Farm 2)**

| S.I No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Net feed waste | D=(CxDa)-Rf | 30 |
| 2 | Net Particulate P load on environment (kg) | Sp=Pp-Rp | 2.1375 |
| 3 | Net N load on environment (kg) | Sn=Pn-Rn | 3 |
| 4 | Net solid load on environment (kg) | S=D+Sp+Sn | 35.1375 |

### 5.4.3 Farm 3: Modelled small scale farm using SIFTS

The amount of nitrogen added into the environment from a farm that uses SIFTS production technique is 21.85kg (see Table 5.9).

**Table 5.9: Mass balance model showing nitrogen loading on a modelled small scale farm using SIFTS per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 0.97 |
| 3 | Feed supply (kg) | C=AxB | 970 |
| 4 | Apparent feed wastage (%) | Da | 10 |
| 5 | Recovery of feed @ 80% | Rf=CxDa/100x80/100 | 77.6 |
| 6 | Net feed wastage (kg) | D=(CxDa)-Rf | 19.4 |
| 7 | Net feed wastage as a percentage | Dw=(D/C)x100 | 2 |
| 8 | Feed consumed (%) | E=C(100-Dw)/100 | 950.6 |
| 9 | Feed undigested (%) | F | 20 |
| 10 | Feacal production (kg) | G=ExF/100 | 190.12 |
| 11 | Nitrogen content of feed (%) | H | 6 |
| 12 | Nitrogen content of feaces (%) | I | 4 |
| 13 | Nitrogen in feed supply (kg) | J=CxH/100 | 58.2 |
| 14 | Nitrogen in feed waste (kg) | K=DxH/100 | 1.164 |
| 15 | Nitrogen ingested (kg) | L=ExH/100 | 57.036 |
| 16 | Nitrogen retained in fish @ 3% (kg) | M=Ax3/100 | 30 |
| 17 | Total nitrogen excreted (kg) | N=L-M | 27.036 |
| 18 | Nitrogen in feaces (kg) | O=Gx I/100 | 7.6048 |
| 19 | Nitrogen in catabolic product (kg) | P=N-O | 19.4312 |
| 20 | Total nitrogen load (kg) | Q=K+O+P | 28.2 |
| 21 | Particulate Nitrogen load (@25%) (kg) | Pn=Qx25/100 | 7.05 |
| 22 | Recovery of particulate nitrogen (@ 90%) (kg) | Rn=PnX90/100 | 6.345 |
| 23 | Net Particulate nitrogen load on environment (kg) | Sn=Pn-Rn | 0.705 |
| 24 | Dissolved nitrogen load(@ 75% (kg) | Dn=Qx75/100 | 21.15 |
| **25** | **Total nitrogen load (kg)** | **Tn=Sn+Dn** | **21.855** |

The system recollects a significant amount of nitrogen and recovers more particulate nitrogen than the net cage farm with a Lift-up system with only 0.705 kg of particulate nitrogen added into the environment (see Table 5.9). It recovers most of the particulate nitrogen and most of the nitrogen added into the environment from this system is in dissolved form (21.15 kg see Table 5.9).

**Table 5.10: Mass balance model showing phosphorus loading on a modelled small scale farm using SIFTS per tonne of rainbow trout produced (Farm 3)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 0.97 |
| 3 | Feed supply (kg) | C=AxB | 970 |
| 4 | Apparent feed wastage (%) | Da | 10 |
| 5 | Recovery of feed @ 80% | Rf=CxDa/100x80/100 | 77.6 |
| 6 | Net feed waste (kg) | D=CXDa/100-Rf | 19.4 |
| 7 | Net feed wastage as a percentage | Dw=(D/C)x100 | 2 |
| 8 | Feed consumed (%) | E=C(100-Dw)/100 | 950.6 |
| 9 | Feed undigested (%) | F | 20 |
| 10 | Feacal production (kg) | G=ExF/100 | 190.12 |
| 11 | Phosphorus content of feed (%) | H | 1.27 |
| 12 | Phosphorus content of feaces (%) | I | 1.5 |
| 13 | Phosphorus in feed supply (kg) | J=CxH/100 | 12.319 |
| 14 | Phosphorus in feed waste (kg) | K=DxH/100 | 0.24638 |
| 15 | Phosphorus ingested (kg) | L=ExH/100 | 12.0726 |
| 16 | Phosphorus retained in fish @ 0.48% (kg) | M=Ax0.48/100 | 4.8 |
| 17 | Total phosphorus excreted (kg) | N=L-M | 7.27262 |
| 18 | Phosphorus in feaces (kg) | O=Gx I/100 | 2.8518 |
| 19 | Phosphorus in catabolic Product (kg) | P=N-O | 4.42082 |
| 20 | Total phosphorus load(kg) | Q=K+O+P | 7.519 |
| 21 | Particulate load @ 75% (kg) | Pp=Qx75/100 | 5.63925 |
| 22 | Recovery of phosphorus @ 80% (kg) | Rp=Ppx 90/100 | 5.07533 |
| 23 | Net phosphorus load on environment (kg) | S=Q-R | 2.44368 |
| 24 | Net particulate 'P' load on environment (kg) | Sp=Pp-Rp | 0.563925 |
| 25 | Dissolved 'P' load(@ 75% (kg) | Dp=Qx75/100 | 5.63925 |
| **26** | **Total phosphorus load (kg)** | **Tp=Sp+Dp** | 6.203175 |

SIFTS reduces the amount of particulate phosphorus added into the environment to only 0.56 kg (see Table 5.10). However, phosphorus lost from the system in dissolved form remains high. The quantity of total solids added into the environment is further reduced on a small scale farm using SIFTS to 20.7 kg (see Table 5.11) for every tonne of rainbow trout produced.

**Table 5.11: Mass balance model showing total solids and nutrient loadings on a modelled SIFTS farm per tonne of rainbow trout produced (Farm 3)**

| S.I No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Net feed waste | D=(CxDa)-Rf | 19.4 |
| 2 | Net Particulate P load on environment (kg) | Sp=Pp-Rp | 0.563925 |
| 3 | Net N load on environment (kg) | Sn=Pn-Rn | 0.705 |
| 4 | Net solid load on environment (kg) | S=D+Sp+Sn | 20.668925 |

Use of SIFTS production technique significantly reduces the amount of particulate nitrogen and phosphorus lost into the environment to 0.7 and 0.6 respectively. The system is efficient in removing particulate nutrients but there is little recovery of dissolved nutrients.

### 5.4.4 Farm 4: Modelled small scale farm using an intergrated closed bag system

On an intergrated small scale aquaculture farm, waste produced from the trout unit is pumped into the trout unit where particulate waste is utilised. Dissolved nutrients are then passed on to the macroalgae unit where algae absorb and utilise the dissolved nutrients. Table 5.12 show the amount of nitrogen produced from the rainbow trout unit.

**Table 5.12: Mass balance model showing nitrogen loading in trout fish unit on a modelled intergrated closed bag system per tonne of rainbow trout produced (Farm 4)**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AXB | 1500 |
| 4 | Feed wastage (%) | D | 10 |
| 6 | Feed consumed (kg) | E=C(100-D)/100 | 1350 |
| 7 | Feed undigested (%) | F | 20 |
| 8 | Feacal production (kg) | G=EXF/100 | 270 |
| 9 | Nitrogen content of feed (%) | H | 6 |
| 10 | Nitrogen content of feaces (%) | I | 4 |
| 11 | Nitrogen in feed supply (kg) | J=CXH/100 | 90 |
| 12 | Nitrogen in feed waste (kg) | K=CxD/100xH/100 | 9 |
| 13 | Nitrogen ingested (kg) | L=EXH/100 | 81 |
| 14 | Nitrogen retained in fish @ 3% (kg) | M=Ax3/100 | 30 |
| 15 | Total nitrogen excreted (kg) | N=L-M | 51 |
| 16 | Nitrogen in feaces (kg) | O=GX I/100 | 10.8 |
| 17 | Nitrogen in catabolic product (kg) | P=N-O | 40.2 |
| 18 | Total nitrogen load (kg) | Q=K+O+P | 60 |
| **19** | **Recovery of nitrogen load if any (kg)** | **R** | **60** |
| 20 | Nitrogen load-particulate @ 13.5% (kg) supply to mullet unit | Np1=Qx13.5/100 | 8.1 |
| 21 | Nitrogen load-dissolved @ 86.5% (kg) supply to macroalgae unit | Nd1=Qx86.5/100 | 51.9 |

In an intergrated system, nitrogen released from the rainbow trout unit is chanelled into the mullet and macroalgae (or floating vegetable) units. The mullet and macroalgae (vegetable) units utilises both particulate and dissolved nitrogen.

**Table 5.13: Mass balance model showing nitrogen utilisation in a modelled mullet unit per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Nitrogen load from fish unit-particulate (kg) | Np1 | 8.1 |
| 2 | Nitrogen transferred to mullet bio-mass @ 25% of supply (kg) | Nm=Np1x25/100 | 2.025 |
| 3 | Nitrogen in faeces @ 25% of supply | Nf=Np1x25/100 | 2.025 |
| 4 | Dissolved nitrogen load @ 50% (kg) | Nd2=Np1x50/100 | 4.05 |
| 5 | Total nitrogen load from mullet unit (kg) | Tn=Nf+Nd2 | 6.075 |
| 6 | recovery of nitrogen load from faeces (kg) | Using sediment trap | 1.5 |
| 7 | Recovery of dissolved nitrogen load (kg) | Supply to macroalgae | 4.575 |
| 8 | Total recovery of nitrogen load from mullet unit (kg) | Item 6+ item 7 | 6.075 |
| 9 | **Nitrogen load from mullet unit on environment (kg)** | **Item5-item 8** | **0** |

The mullet unit utilises some of the particulate nitrogen lost from the rainbow trout unit. Mullet feed on particulate waste coming from the rainbow trout unit, so the unit mostly removes particulate nitrogen. Sediment traps are then used to trap remaining particulate nitrogen before the dissolved nitrogen is pumped into the macroalgae (or vegetable unit).

**Table 5.14: Mass balance model showing nitrogen utilisation in macroalgae unit on a modelled small scale intergrated closed bag system per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Dissolved nitrogen load of fish unit (kg) | Nd1 | 51.9 |
| 2 | Dissolved nitrogen load of mullet unit (kg) | Nd2 | 4.05 |
| 3 | Total dissolved nitrogen load on macroalgae unit (kg) | Nd=Nd1+Nd2 | 55.95 |
| 4 | Dissolved nitrogen utilized by macroalgae unit (kg) | | 55.95 |
| **5** | **Net nitrogen load from macroalgae unit on environment** | **Item3-Item 4** | **0** |

Dissolved nitrogen released from trout and mullet units is utilised by the macroalgae unit with net load of dissolved nitrogen to the environment of zero. The intergrated system ensures removal of both dissolved and particulate nitrogen from the system.

Tables 5.15, 5.16 and 5.17 show the movement and utilisation of phosphorus in an intergrated system. 9.975 kg of particulate phosphorus waste produced from the rainbow trout unit is pumped into the mullet unit. Dissolved phosphorus produced in the rainbow trout unit of 4.275kg is supplied to the macroalgae unit where it is utilised.

**Table 5.15: Mass balance model showing phosphorus loading in a rainbow trout unit on a modelled small scale intergrated closed bag system per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Fish production (kg) | A | 1000 |
| 2 | Feed conversion rate | B | 1.5 |
| 3 | Feed supply (kg) | C=AXB | 1500 |
| 4 | Feed wastage (%) | D | 10 |
| 6 | Feed consumed (kg) | E=C(100-D)/100 | 1350 |
| 7 | Feed undigested (%) | F | 20 |
| 8 | Feacal production (kg) | G=EXF/100 | 270 |
| 9 | Phosphorus content of feed (%) | H | 1.27 |
| 10 | Phosphorus content of feaces (%) | I | 1.5 |
| 11 | Phosphorus in feed supply (kg) | J=CXH/100 | 19.05 |
| 12 | Phosphorus in feed waste (kg) | K=CxD/100xH/100 | 1.905 |
| 13 | Phosphorus ingested (kg) | L=ExH/100 | 17.145 |
| 14 | Phosphorus retained in fish @ 0.48% (kg) | M=Ax0.48/100 | 4.8 |
| 15 | Total phosphorus excreted (kg) | N=L-M | 12.345 |
| 16 | Phosphorus in feaces (kg) | O=Gx I/100 | 4.05 |
| 17 | Phosphorus in catabolic product (kg) | P=N-O | 8.295 |
| 18 | Total phosphorus load (kg) | Q=K+O+P | 14.25 |
| **19** | **Recovery of phosphorus load (kg)** | **R** | **14.25** |
| **20** | **Phosphorus load-particulate @ 70% (kg) supply to mullet unit** | **Pp1=Qx70/100** | **9.975** |
| **21** | **Phosphorus load-dissolved @ 30% (kg) supply to macroalgae unit** | **Pd1=Qx30/100** | **4.275** |

**Table 5.16: Mass balance model showing phosphorus loading in mullet unit on a modelled small scale intergrated closed bag system per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Phosphorus load from trout unit-particulate (kg) | Pp1 | 9.975 |
| 2 | Phosphorus transferred to mullet bio-mass @ 25% of supply (kg) | Pm=Pp1x25/100 | 2.49375 |
| 3 | Phosphorus in faeces @ 50% of supply | Pf=Pp1x50/100 | 4.9875 |
| 4 | Dissolved phosphorus load @ 25% (kg) | Pd2=Pp1x25/100 | 2.49375 |
| 5 | Total phosphorus load from mullet unit (kg) | Pn=Pf+Pd2 | 7.48125 |
| 6 | Recovery of phopshorus load from faeces (kg) | Using sediment trap | 1.75 |
| 7 | Recovery of dissolved phosphorus load (kg) | Supply to macroalgae | 5.73125 |
| 8 | Total recovery of phosphorus load from mullet unit (kg) | Item 6+ item 7 | 7.48125 |
| 9 | **Phosphorus load from mullet unit on environment (kg)** | **Item5-item 8** | **0** |

The mullet unit utilises particulate phosphorus coming from the trout unit and the remaining particulate phosphorus is removed from the system using sediment traps. Particulate phosphorus is totally removed from the system using sediment traps in the mullet unit before water is pumped into the macroalgae unit.

**Table 5.17: Mass balance model showing phosphorus loading on macroalgae unit on a modelled small scale intergrated closed bag system per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| 1 | Dissolved phosphorus load of trout unit (kg) | Nd1 | 4.275 |
| 2 | Dissolved phosphorus load of mullet unit (kg) | Nd2 | 2.49375 |
| 3 | Total dissolved phosphorus load on macroalgae unit (kg) | Nd=Nd1+Nd2 | 6.76875 |
| 4 | Dissolved phosphorus utilized by macroalgae unit (kg) | | 6.76875 |
| **5** | **Net phosphorus load from macroalagae unit on environment (kg)** | **Item3-Item 4** | **0** |

Dissolved phosphorus is then pumped into the macroalgae (or vegetable) unit. It is important to remove particulate phosphorus and nitrogen before water is pumped into the macroalgae unit as macroalgae can only utilise dissolved nutrients. The system effectively removes dissolved and particulate phosphorus from the system. The ability of the system to remove dissolved phosphorus is of great importance in fresh water aquaculture as phosphorus is the primary nutrient that causes eutrophication in freshwater bodies. Phosphorus concentration also limits stocking rates on aquaculture farms.

**Table 5.18: Mass balance model showing total solid loading to the environment on a modelled small scale intergrated closed bag system per tonne of rainbow trout produced**

| S.I. No | Item | Formula | Estimation |
|---|---|---|---|
| **Outflow from fish unit** | | | |
| 1 | Particulate waste from trout unit supplied to mulletl unit (kg) | A=Np1+Pp1 | 18.075 |
| 2 | Recovery of particulate waste from fish unit by mullet unit | R 1 | 18.075 |
| 3 | Net particulate waste from trout unit | S1=A-R1 | 0 |
| **Outflow from mullet unit** | | | |
| 1 | Particulate waste from trout unit supplied to mullet unit (kg) | A | 18.075 |
| 2 | Transfer of nutrient to mullet unit as biomass | B=Nm+Pm | 4.51875 |
| 3 | Dissolved nutrient released from the mullet unit | C=Nd2+Pd2 | 6.54375 |
| 4 | Solid waste from the unit (gross) | Sg=A-(B+C) | 7.0125 |
| 5 | Recovery of solid waste from mullet unit using sediment | R 2 | 7.0125 |
| 6 | Solid waste from the mullet unit | S2=Sg-R2 | 0 |
| **Outflow from macroalgae unit** | | | |
| 1 | Solid waste | S3=S1+S2 | 0 |
| **Total solids load** | | | |
| 1 | Total solids (SS) load | SS=S1+S2+S3 | 0 |

Total solids load from an intergrated trout-mullet-macroalgae system is zero as indicated in Table 5.18. Most of the suspended solids from the trout unit are consumed by the mullet and remaining solid waste is recovered using sediment traps. Dissolved nitrogen and phosphorus leaving the system is equal to zero as all the nutrients are extracted from the water by the aquatic organisms grown. The system recovers both dissolved and particulate nutrients with the grown species converting the waste.

## 5.5 Comparison of nutrient loading for the alternative production techniques

The four modelled small scale farms were assumed to be using the same type of trout feed from Aquanutro. The aim was to compare waste loading and waste recovery on farms using the alternative production techniques. A summary of the results of nutrient loading analysis are presented in Tables 5.19 and 5.20.

**Table 5.19: Summary of mass balance model showing nitrogen loading on the modelled farms using different production techniques per tonne of rainbow trout produced**

| Item | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| System | Net cage | Net cage with Lift up | SIFTS | Intergrated closed bag system |
| Feeding | Hand feeding | Hand feeding | Hand feeding | Hand feeding |
| Feed | Aquanutro | Aquanutro | Aquanutro | Aquanutro |
| Feed wastage (%) | 10 | 10 | 10 | 10 |
| Food conversion rate | 1.5 | 1.5 | 0.97 | 1.5 |
| N' content of feed (%) | 6 | 6 | 6 | 6 |
| Fish production (kg) | 1000 | 1000 | 1000 | 1000 |
| Feed used (kg) | 1500 | 1500 | 970 | 1500 |
| Feed waste (kg) | 150 | 30 | 19.4 | 9 |
| Feed consumed (kg) | 1350 | 1470 | 950.6 | 1350 |
| % undigested feed | 20 | 20 | 20 | 20 |
| Feacal production (kg) | 270 | 294 | 190.12 | 270 |
| N' supplied in feed (kg) | 90 | 90 | 58.2 | 90 |
| N' in feed waste (kg) | 9 | 1.8 | 1.164 | 9 |
| N' ingested (kg) | 81 | 88.2 | 57.036 | 81 |
| N' retained in fish (kg) | 30 | 30 | 30 | 30 |
| Total 'N' excreted (kg) | 51 | 58.2 | 27.036 | 51 |
| N' in faeces (kg) | 10.8 | 11.76 | 7.6048 | 10.8 |
| N'excreted as catabolic product (kg) | 40.2 | 46.44 | 19.4312 | 40.2 |
| Total 'N' load (kg) | 60 | 60 | 28.2 | 60 |
| Recovery of 'N' load (kg) | 0 | 12 | 6.345 | 60 |
| **N' load on environment (kg)** | **60** | **48** | **21.855** | **0** |

*Note:* **N'- Nitrogen**

Tables 5.19 and 5.20 show that the use of intergrated production technique is the most effective way of reducing nutrient loading in water based aquaculture systems. When the intergrated production technique is used, all the nutrients and dissolved solids are recovered and used within the system. The most important component of the intergrated system is in determining biological relationships of the aquatic species and pumping rate of water from one unit to another that results in total removal of nutrients.

**Table 5.20: Summary of mass balance model showing phosphorus loading on modelled farms using different production techniques per tonne of rainbow trout produced**

| Item | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| Feeding system | Hand feeding | Hand feeding | Hand feeding | Hand feeding |
| Feed | Aquanutro | Aquanutro | Aquanutro | Aquanutro |
| Feed wastage (%) | 10 | 10 | 10 | 10 |
| Food Conversion rate | 1.5 | 1.5 | 0.97 | 1.5 |
| P' content of feed (%) | 1.27 | 1.27 | 1.27 | 1.27 |
| Fish production (kg) | 1000 | 1000 | 1000 | 1000 |
| Feed used (kg) | 1500 | 1500 | 970 | 1500 |
| Feed waste (kg) | 150 | 30 | 19.4 | 150 |
| Feed consumed (kg) | 1350 | 1470 | 950.6 | 1350 |
| Percentage undigested feed | 20 | 20 | 20 | 20 |
| Feacal production (kg) | 270 | 294 | 190.12 | 270 |
| P' supplied in feed (kg) | 19.05 | 19.05 | 12.319 | 19.05 |
| P' in feed waste (kg) | 1.905 | 0.381 | 0.24638 | 1.905 |
| P' ingested (kg) | 17.145 | 18.669 | 12.07262 | 17.145 |
| P' retained in fish (kg) | 4.8 | 4.8 | 4.8 | 4.8 |
| Total 'P' excreted (kg) | 12.345 | 13.869 | 7.27262 | 12.345 |
| P' in faeces (kg) | 4.05 | 4.41 | 2.8518 | 4.05 |
| P'excreted as catabolic product (kg) | 8.295 | 9.459 | 4.42082 | 8.295 |
| Total 'P' load (kg) | 14.25 | 14.25 | 7.519 | 14.25 |
| Recovery of 'P' load (kg) | 0 | 8.55 | 5.075325 | 14.25 |
| **P' load on environment (kg)** | **14.25** | **5.7** | **2.443675** | **0** |

*Note:* P'-phosphorus

The intergrated production technique is then followed by the SIFTS technique in terms of effectiveness of removing waste and nutrients added into the environment. The ability of SIFTS production technique to quickly recover waste before it completely disintergrates ensures that part of the nutrients lost in the Lift-up system as dissolved nutrients is recovered. The Lift-up system is the third production technique option in terms of effectiveness in removing waste and nutrients from aquaculture. The system significantly reduces the amount of solid waste loading into the environment but a large portion of nitrogen and phosphorus is lost as dissolved nutrients.

SIFTS and Lift-up systems are mechanical methods of removing waste and they are mostly effective in removing particulate waste, but not dissolved nutrients. Hence the intergrated system is better as it deals with both the particulate and dissolved nutrients. On a small scale net cage farm where there is no recovery of waste, a large amount of solids are added into the environment and negative environmental impacts are more likely to occur on such a farm in the long run. Recovering waste improves fish production as it prevents self pollution of fish production units and it also reduces incidences of disease outbreaks caused by waste. Using net cages without any method of recovering waste reduces the life span of aquaculture production site as aquaculture activities will have to stop if the accumulative impacts of waste cause changes in water quality.

Nitrogen and phosphorus loading from the alternative production techniques also follows a similar trend observed for accumulation of total solids. The intergrated system results in zero nitrogen and phosphorus loading because nutrients are recycled by the organisms that feed at different trophic levels in the system. It is the most effective system for dealing with dissolved nitrogen and phosphorus followed by SIFTS. The ability of SIFTS to quickly remove waste before it completely dissolve, results in recovery of more nutrients as compared to the Lift-up system. Mechanical systems are effective in removing particulate nitrogen and phosphorus hence dissolved nutrients would always be of great concern when these systems are used. The ability of the intergrated system to remove dissolved nutrients makes it the most suitable production technique for future developments of water based aquaculture. Non-recovery of nutrients on modelled Farm 1 will result in lower stocking rates for the net cage farm so as to avoid negative environmental impacts.

## 5.6 Capital investments of modelled small scale trout farms using different production techniques

Based on data collected from small scale farms survey, contacts (in Denmark and Australia) and secondary data, capital investment budgets were prepared for the modelled small scale rainbow trout farms using the alternative production techniques. The capital investments budgets were prepared based on guidelines from Boehlje and Eidman (1984). For the Lift-up system, costs of the system were obtained from a distribution agent based in Denmark (HVALPSUND) and converted to local currency. Additional costs were then included for importation of the system. For the Australian made SIFTS system, current prices of the system could not be obtained as the system is not being produced at the moment and it is only produced. A price estimate based on figures of the previous system produced was used.

Valuation of fixed improvements and equipment differs in periods of high and low inflation (The Standard Bank, 2005). In periods with low inflation, assets are valued at cost price less accumulated depreciation. In periods of high inflation, assets are valued at replacement value less accumulated depreciation. In this study, cost price less accumulated depreciation was used because of the prevailing periods of low inflation. It was assumed that the initial capital investment of the modelled farms will be in year one and depreciation was calculated for preceeding years using the straight line method. The annual depreciation will therefore be the same for every year of the expected lifetime of the asset. Table 5.21 summarises initial capital investment for the four modelled farms using different production techniques.

**Table 5.21: Capital investment of modelled small scale trout farms using different production techniques**

| Capital investment | Net-cage farm (Farm 1) (R) | Net cage farm with Lift-up (Farm 2) (R) | SIFTS (Farm 3) (R) | Intergrated farm (Farm 4) (R) |
|---|---|---|---|---|
| **Fixed improvements:** | | | | |
| Cages | 110 000 | 160 000 | 1 000 000 | 360 000 |
| Wendy house | 0 | 0 | 30 000 | 30 000 |
| Demand feeder system | 0 | 0 | 0 | 60 000 |
| Total | 110 000 | 160 000 | 1 030 000 | 450 000 |
| **Moveable assets:** | | | | |
| Nets, scoops and scales | 3 000 | 3 000 | 3000 | 30 000 |
| Other equipment expenses | 14 500 | 33 000 | 0 | 51806 |
| Total | 127 500 | 196 300 | 1 033 000 | 501806 |

Farm 3 (SIFTS) has a huge initial investment cost compared to the other three farms because the system is a new design that will require to be imported and transported from Australia. On Farm 1 and Farm 2 there is no cost of Wendy house because the farms handle smaller amounts of feeds and the farmers can use rented storage space on the farm to store feed. For Farm 3 and farm 4, a Wendy house is required since the farmers would require storing large amounts of feeds. This assessment is handicapped owing to the limited access to information related to the current price of the SIFTS from the company that produces it. It is important to note that the inaccuracies of this report due to lack of information on current price of the SIFTS could not be avoided. However use of the estimated costs based on the previous system manufactured was regarded as enough in order to carryout out the comparative cost/benefit analysis of the alternative production techniques.

## 5.7 Comparison of the financial performance of alternative production techniques

The four farms described in the previous section were compared in financial terms. The core of the comparative analysis was an investment appraisal of the small scale rainbow trout farms. The income and cost data was based on indicative values of efficiently operated small scale rainbow trout farms using different production techniques. Costs and benefits for each farm were calculated based on investment costs and operational costs of the farm compared to expected income from projected harvest at each farm over a period of ten years.

Typical small scale trout farm budget information solicited from the different farmers and information obtained from Hands-On Fish Farmers Cooperative was aggregated into typical small scale trout farm budgets as presented in Table 5.22. Gross income was calculated by multiplying fish harvests (yield) by the selling price of rainbow trout as shown in Table 5.22. Direct production costs such as fingerlings, feed, veterinary fees and marketing costs were summed together to get total direct production costs. Indirect costs namely, wages, transport, maintenance, administration and equipment expenses were added to direct production costs to get the total operating expenditure. Total operating costs were then deducted from gross income to get margins above specified costs. Fixed costs such as depreciation were subtracted from margins above specified costs to get the net farm incomes (see Table 5.22).

**Table 5.22: Financial performance of modelled typical small scale rainbow trout farms using different production techniques**

| | Farm 1 (Net cage) | Farm 2 (Net cage with Lift-up) | Farm 3 (SIFTS) | Farm 4 (Intergrated system) |
|---|---|---|---|---|
| **Farm Income** | | | | |
| Harvest in kg/farm | 8 200 | 9 960 | 40 000 | 32 000 |
| Price of fish (R/kg) | 31.35 | 31.35 | 31.35 | 31.35 |
| **Gross Farm Income** | **257 070** | **312 246** | **1 254 000** | **1 003 200** |
| **Direct Production Costs** | | | | |
| Fingerlings @ R44/kg of smolt | 68 200 | 74 360 | 278 960 | 162 800 |
| Fish Food @ R7.12/kg | 87 576 | 106 373 | 284 800 | 341 760 |
| Veterinary fees | 3 000 | 3 000 | 3 000 | 3 000 |
| Marketing costs | 2 500 | 2 500 | 3 000 | 6 000 |
| **Total Direct Production Costs** | **161 276** | **186 233** | **569 760** | **513 560** |
| **Indirect Costs** | | | | |
| Wages & Salaries | 14 400 | 14 400 | 14 400 | 14 400 |
| Transport & Fuel | 4 650 | 4 650 | 9 300 | 30 150 |
| Electricity | 0 | 0 | 21 000 | 30 150 |
| Maintenance | 2 000 | 1 000 | 50 000 | 10 000 |
| Administration | 2 400 | 2 400 | 2 400 | 20 100 |
| Equipment Expenses | 2 000 | 1 000 | 2 000 | 36 150 |
| **Operating Costs** | **186 726** | **209 683** | **668 860** | **654 510** |
| Miscellenous @ 5% of operating costs | 9 336 | 10 484 | 33 443 | 32 726 |
| Margin above specified costs | 61 008 | 92 079 | 551 697 | 315 965 |
| **Other Fixed Costs** | | | | |
| Depreciation on cages @12.5% p.a. | 13 750 | 20 000 | 100 000 | 45 000 |
| Depreciation of nets @25% p.a. | 750 | 750 | 750 | 7 500 |
| **Net Farm Income** | **46 508** | **71 329** | **450 947** | **263 465** |
| Rental | 14 400 | 14 400 | 100 000 | 60 000 |
| **Farm Profit or Loss** | **32 108** | **56 929** | **350 947** | **203 465** |

## 5.8 Multi-period budgets for the farms

Multi-period budgets for a period of ten years were prepared for modelled small scale rainbow trout farms using different production techniques and the results will be discussed in the next sections.

### 5.8.1 Farm 1: Modelled small scale rainbow trout farm using net cage system

The multi-period budget for a modelled typical small scale net cage farm in Table 5.23 indicates that costs outweigh benefits in the first year due to the high initial investment costs.

**Table 5.23: Multi-period budget for a modelled typical small scale net cage farm in the Western Cape**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total farm inflows** | **257 070** | **257 070** | **257 070** | **257 070** | **257 070** | **231 363** | **231 363** | **231 363** | **231 363** | **300 113** |
| Investment cost | 127 500 | 0 | 0 | 0 | 3 000 | 0 | 0 | 110 000 | 3 000 | 0 |
| Operating costs | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 | 210 462 |
| **Total farm outflows** | **337 962** | **210 462** | **210 462** | **210 462** | **213 462** | **210 462** | **210 462** | **320 462** | **213 462** | **210 462** |
| **Net Annual Flow** | **-80 892** | **46 608** | **46 608** | **46 608** | **43 608** | **20 901** | **20 901** | **-89 099** | **17 901** | **89 651** |
| IRR | 46% | | | | | | | | | |
| BCR | 1.121 | | | | | | | | | |
| NPV | R 93 705 | | | | | | | | | |

*Note:* *Inflow in the 6th year decreases because production on the farm has to be reduced due to effects of accumulation of waste in the dam

** In the 10th year, total farm inflows increases because the residual value of assets is added to the inflows at the end of the project life period in the analysis.

*** A discount rate of 8 percent was used

From the second year onwards benefits outweigh costs as indicated by positive net annual cash flows. Nets, scales and scoops are replaced after every four years of use and the cages are also replaced after 8 years. Negative net cash flow in the 8th year is due to replacement of cages. The farm has a positive net present value of R93 705 (see Table 5.23) indicating that rainbow trout farming using net cages is financially viable. A BCR of 1.121 which is greater than one indicate that benefits outweigh costs and there will be positive returns on investment. The internal rate of return for the small scale rainbow trout farm is 46 percent which is greater than the cost of capital (8 percent) showing that small scale rainbow trout farming is a financially worth investment.

### 5.8.2 Farm 2: Modelled small scale net cage farm with a Lift-up system

A multi-period budget of a modelled typical small scale net cage farm fitted with a Lift-up system is presented in Table 5.24. It shows that rainbow trout farming using a net cage system with a Lift-up system is a viable option as indicated by a positive NPV of R308 347. A BCR ratio of 1.201 shows that benefits outweigh costs and the farmer gets R1.20 for every R1 invested in rainbow trout farming. Table 5.24 also shows an IRR of 63 percent that is well above the opportunity cost of money (8 percent) showing that investment in rainbow trout farming using net cages fitted with a Lift-up system is financially viable.

There is a difference in NPV of Farm 1 and Farm 2 of R214 000 indicating that adding the Lift-up system will give extra financial benefits to the farmer. In addition to monetary benefits, there are also environmental and social benefits that will arise as a result of recovery of waste that are not reflected in this financial analysis, but will be presented in Chapter 6.

**Table 5.24: Multi-period budget for a modelled small scale net cage farm with a Lift-up sytem**

| **Year** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total farm inflows** | **312 246** | **312 246** | **312 246** | **312 246** | **312 246** | **312 246** | **312 246** | **312 246** | **312 246** | **380 996** |
| Investment costs | 196 300 | 0 | 0 | 0 | 3 000 | 0 | 0 | 110 000 | 3 000 | 0 |
| Operating costs | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** | **234 567** |
| **Total farm outflows** | **430 867** | **234 567** | **234 567** | **234 567** | **237 567** | **234 567** | **234 567** | **344 567** | **237 567** | **234 567** |
| **Net Annual Flow** | **-118 621** | 77 679 | 77 679 | 77 679 | 74 679 | 77 679 | 77 679 | -32 321 | 74 679 | 146 429 |
| IRR | 63% | | | | | | | | | |
| BCR | 1.201 | | | | | | | | | |
| NPV | R 308 347 | | | | | | | | | |

***Note:*** * A discount rate of 8 percent was used

**Inflows for this farm are uniform for the first nine years as the same level of production can be maintained throughout because waste is removed.

*** In the 10th year, total farm inflows increases because the residual value of assets is added to the inflows at the end of the project life period in the analysis.

Recovery of waste on Farm 2 prolongs the life span of aquaculture farming in dams. The agreement that small scale rainbow trout farmers and the farm owner enter into requires maintenance of good water quality and aquaculture will cease operations if water quality significantly changes.

### 5.8.3 Farm 3: Modelled small scale rainbow trout farm using SIFTS

The financial analysis results of a modelled typical small scale farm using SIFTS production technique are presented in Table 5.25.

**Table 5.25: Multi-period budget for a modelled small scale farm using SIFTS**

| **Year** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total farm inflows** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** | **1 254 000** |
| Investment costs | 1 033 000 | 0 | 0 | 0 | 33 000 | 0 | 0 | 0 | 33 000 | 0 |
| Operating costs | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** | **802 303** |
| **Total farm outflows** | **1 835 303** | 802 303 | 802 303 | 802 303 | 835 303 | 802 303 | 802 303 | 802 303 | 835 303 | 802 303 |
| **Net Annual Flow** | **-581 303** | **451 697** | **451 697** | **451 697** | **418 697** | **451 297** | **451 697** | **451 697** | **418 697** | **451 697** |
| IRR | 77% | | | | | | | | | |
| BCR | 1.385 | | | | | | | | | |
| NPV | R 2 035 222 | | | | | | | | | |

Note:* A discount rate of 8 percent was used

**Inflow for this farm is uniform throughout because the farmer can use the same stocking rates throughout because there will be no water quality related problems due to accumulation of waste.

*** For SIFTS system, the economic life of the system is ten years hence at the end of the project life the value of the system is assumed to be zero.

The modelled small scale farm using SIFTS production technique requires huge initial investment costs and net annual cashflow in the first year is negative. In the fifth and ninth year, the Wendy house and scales are replaced. The small scale farm using SIFTS production technique has a NPV of R2 035 222 indicating that rainbow trout farming using SIFTS is financially viable. A BCR of 1.385 shows that the investor gets higher returns on every Rand invested. Table 5.26 show an IRR of 77 percent which is significantly higher than the cost of capital (8 percent). It indicates that investing in rainbow trout farming using SIFTS production technique is financially rewarding.

### 5.8.4 Farm 4: Modelled small scale intergrated closed bag system

Table 5.26 show a multi-period budget of a small scale intergrated rainbow trout farm. The farm shows a positive NPV of R410 222 indicating that rainbow trout farming using intergrated systems is financially viable. A BCR of 1.07 that is greater than one indicates that benefits outweigh costs.

**Table 5.26: Multi-period budgets for a modelled small scale farm using intergrated closed bag system.**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Total farm inflows** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 003 200** | **1 228 200** |
| Investment costs | **501 086** | **0** | **0** | **0** | **30 000** | **0** | **0** | **360 000** | **30 000** | **0** |
| Operating costs | **747 236** | 826 822 | 826 822 | 826 822 | 826 822 | 826 822 | 826 822 | 1 303 082 | 826 822 | 826 822 |
| **Total farm outflows** | **1 248 322** | **826 822** | **826 822** | **826 822** | **856 822** | **826 822** | **826 822** | **1 663 082** | **856 822** | **826 822** |
| **Net Annual Flow** | **-245 122** | 176 378 | 176 378 | 176 378 | 146 378 | 176 378 | 176 378 | -659 882 | 146 378 | 401 378 |

| | |
|---|---|
| **IRR** | **64%** |
| **BCR** | **1.070** |
| **NPV** | **R410 222** |

*A discount rate of 8 percent was used.

**Income from mullet and macroalgae unit was not included in this analysis.

** *In the 10th year, total farm inflows increases because the value of assets is added to the inflows at the end of the project life period in the analysis.

On this particular farm, cages are replaced in the 8th year. This farm has the second highest NPV for the four modelled small scale trout farms. IRR of 64 percent which is significantly higher than the interest rate of borrowing money (8 percent) indicates that fish production using the integrated system is a good investment that will give good returns to the farmer. It is important to note that the intergrated system show positive returns even though income from the mullet unit is not included in the analysis.

## 5.9 Comparison of financial benefits of using the alternative production techniques

Results of financial analysis of using the alternative production techniques to produce rainbow trout are presented in Table 5.27. The net present values (NPV) of all the farms are positive indicating that investment in rainbow trout farming using all the production techniques is financially viable as benefits outweigh costs.

**Table 5.27: Financial performance of aquaculture farms using different production techniques**

| | **Farm 1** | **Farm 2** | **Farm 3** | **Farm 4** |
|---|---|---|---|---|
| **NPV (R)** | R 93 705 | R 308 347 | R 2 035 222 | R 410 222 |
| **BCR** | 1.121 | 1.20 | 1.385 | 1.070 |
| **IRR (%)** | 46% | 63% | 77% | 64% |
| **Production costs (R/kg)** | R 24.53 | R 22.50 | R 21.97 | R 22.64 |

Based on the assumption that recovery of waste and nutrients enables a farmer to use higher stocking rates for Farm 2 than Farm 1, the financial benefit of using the Lift-up system to the farmer is R214 00. Although Farm 1 indicates a positive NPV, there is a huge environmental cost that is likely to arise in the long run as a result of accumulation of organic waste in the dam that is not reflected in the financial analysis. If recovered waste from Farm 2 and Farm 3 is converted into valuable products like compost, the benefits of removing waste will be more. There are other non-monetary benefits that the farmer will get that are not reflected in the financial analysis that were estimated using the contingent valuation method that will be presented in Chapter 6.

In using a more efficient production technique that quickly removes waste like Farm 3 (SIFTS), a higher NPV of R2 million is obtained by the farmer. The benefits of using such a system are quite large as indicated by the R1.9 million differences in NPV for Farm 3 with Farm 1. Farm 4, an intergrated closed bag system also has a positive NPV of R410 222. In ranking the production techniques, the SIFTS system is ranked as the first option for the farmer as it produces the greatest NPV. The second option will be using the intergrated closed bag system as it is the production technique with the second highest NPV. However, in the analysis, income from mullet unit was not considered and net present value of the intergrated system is higher than the indicated and if included the system would compare better to the SIFTS system. The third best option for the farmer will be to use net cage with a Lift-up system. Table 5.27 also indicate that rainbow trout production with techniques that recover waste generate huge financial benefits as compared to Farm 1 where there is no waste recovery. The difference in NPV of farms with waste recovery and Farm 1 where there is no waste recovery can be attributed to higher fish stocking rates and production of better quality fish.

The calculated internal rates of return for all four aquaculture production techniques are significantly higher than the opportunity cost of capital (8 percent). This indicates that rainbow trout farming using the alternative production techniques is financially viable and gives high returns. The benefit cost ratio (BCR) for all the alternatives is greater than 1 indicating that all the production techniques generate benefits that are greater than costs over their life period. Ranking the options using BCR, Farm 3 using SIFTS has the highest BCR of 1.385 showing that the project will give the highest returns. The second option is Farm 2, a net cage farm with Lift-up that has BCR of 1.2. The third option is the small scale net cage farm that shows BCR of 1.121 and the last option would be the small scale intergrated farm (Farm 4).

Table 5.27 show a price of fish of R31.35 per kg which is greater than production costs for all the production techniques. SIFTS production technique is the cheapest production technique to produce a kilogram of rainbow trout (see Table 5.27). The cost of production using SIFTS is R21.97 (see

Table 5.27) for every kilogram of rainbow trout produced and the second cheapest production technique is the net cage farm with a Lift-up system where the cost of producing a kilogram of rainbow trout is R22.50. The most expensive production technique is the net cage farm without any method of recovering waste where R24.53 is required to produce a kilogram of fish. The trend shows that costs of production decreases as scale of production increases (economies of scale) in fish production.

## 5.10 Sensitivity analysis

Fingerling and feed prices are the two most important variable cost items in rainbow trout production that take up a huge portion of an aquaculture farm budget. The percentages taken by variable costs on a small scale trout farm budget were calculated and are presented in Table 5.28. It shows that feed is the highest variable cost item for all of the production techniques except Farm 3 using SIFTS system. The percentage cost of feed is lower than percentage cost of fingerling due to the high stocking rates and better feed management in this system (FCR of 0.97).

**Table 5.28: Structure of costs of production on modelled farms using different techniques**

| Item | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| **Fingerlings (%)** | 32.1 | 32.8 | 39.5 | 32.1 |
| **Feed (%)** | 48.75 | 49.8 | 38.8 | 48.8 |
| **Other operating costs (%)** | 19.25 | 17.4 | 21.7 | 19.1 |

Feed is the highest variable cost in trout production in South Africa. Feed prices are likely to increase in future as the price is mainly influenced by the raw materials required for feed production. Monopoly in the feed industry is one factor that was mentioned by the farmers as contributing to the high feed costs. Farmers indicated that feed prices are more likely to increase in future unless there is an increase in feed imports, something that is less likely to happen considering the stringent regulations that govern importation of fish products into South Africa. A sensitivity analysis was carried out to determine the viability of production techniques if feed prices are to increase in future and results are presented in Table 5.29.

### 5.10.1 Sensitivity of NPV of modelled farms to feed price increase

Table 5.29 show the results of the sensitivity analysis of financial viability of small scale rainbow trout farms that use different production techniques. If price of feed increases by 10 percent, NPV of all the small scale rainbow trout farms decreases but remains positive.

**Table 5.29: Sensitivity analysis of net present value of different production techniques to 10 percent increase in feed prices**

| | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| **NPV (R)** | 34 941 | 236 970 | 1 844 119 | 199 362 |
| **BCR** | 1.079 | 1.154 | 1.333 | 1.037 |
| **IRR (%)** | 24% | 48% | 68% | 36% |

Table 5.29 shows that Farm 3 (SIFTS) remains the production technique with the highest returns as indicated in Table 5.29. A change in price of feed will only lower the net benefits of fish production but fish farming remains viable with all the production techniques. On ranking the techniques, SIFTS remains the technique that generates the highest benefits and net cage farm without waste recovery (Farm 1) will be the least profitable option as indicated in Table 5.29. BCR and IRR also indicate that all projects remain viable with IRR greater than the cost of capital (interest rate) showing that fish farming using any of the four production techniques will remain viable even if the price of feed increases by 10 percent in future.

### 5.10.2 Sensitivity of NPV of modelled farms to trout fingerlings price increase

Fingerling prices is one of the cost parameters that take up a siginificant proportion of the cost budget for aquaculture production as indicated in Table 5.28. Over the past seven years, fingerling prices have been increasing in the Western Cape as indicated in Table 5.30 and the trend is expected to continue in future. The average annual increase in price of fingerling from 2003 to 2010 was 7.9 percent (calculated from data in Table 5.30).

**Table 5.30: Price of trout fingerlings over the past 7 years**

| Year | Fish size(cm) | Fish weight (grams) | Number of fish/kg | Price (R/kg) | Price Incl. vat @ 14% |
|---|---|---|---|---|---|
| 2003 | 23-25 | 140-180 | 5 to 7 | 27 | 30.78 |
| 2004 | 23-25 | 140-180 | 5 to 7 | 28 | 31.92 |
| 2005 | 23-25 | 140-180 | 5 to 7 | 40 | 45.6 |
| 2006 | 23-25 | 140-180 | 5 to 7 | 40 | 45.6 |
| 2008 | 23-25 | 140-180 | 5 to 7 | 40 | 45.6 |
| 2010 | 23-25 | 140-180 | 5 to 7 | 44 | 50.16 |

If price of fingerlings increases by 10 percent per annum, viability of using the alternative production techniques will change as indicated in Table 5.31.

**Table 5.31: Sensitivity analysis of net present value of farms if price of fingerlings increase by 10 percent**

| | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| **NPV** | R 47 942 | R 258 451 | R 1 848 038 | R 309 777 |
| **BCR** | 1.088 | 1.168 | 1.334 | 1.054 |
| **IRR** | 29% | 52% | 68% | 50% |

A 10 percent annual increase in fingerling prices will result in a decrease in net present values of all the production techniques. However the increase in price of fingerlings does not affect financial viability of rainbow trout production using the techniques as all the NPV remain positive indicating that all the farms will remain viable. An increase in price of fingerlings does not change the ranking of the projects using NPV and IRR. Ranking using BCR, Farm 3 a farm using SIFTS is still the farm with the highest BCR followed by Farm 2 (net cage with Lift-up) and Farm 1 (net cage) and lastly Farm 4 (intergrated system). SIFTS production technique remains the production option ranked first with the highest NPV. IRR for all the alternatives also remains well above the interest rate indicating that the alternative production techniques will still give high returns to the farmers even if price of fingerlings is to increase. BCR for all the projects is still greater than one indicating that if price of fingerlings increase by 10 percent, benefits will still outweigh costs for all the projects.

### 5.10.3 Sensitivity analysis of NPV of modelled farms to rainbow trout price decrease

If price of rainbow trout decreases by 10 percent, financial viability of the small scale farms change as shown in Table 5.32. Results in Table 5.32 indicate that fish production using two of the four production techniques will no longer be viable if price decreases by 10 percent. Farm 3 (SIFTS) and Farm 2 (net cage with Lift-up) remains viable if price of rainbow trout decreases.

**Table 5.32: Sensitivity analysis of NPV of farms if trout price decrease by 10 percent**

| | **Farm 1** | **Farm 2** | **Farm 3** | **Farm 4** |
|---|---|---|---|---|
| **NPV (R)** | -R71 806 | R125 597 | R1 193 778 | -R262 934 |
| **BCR** | 1.013 | 1.095 | 1.237 | 0.965 |
| **IRR (%)** | _ | 31% | 44% | - |

A decrease in price of rainbow trout will have greatest impact on viability of the intergrated closed bag system (Farm 4) than any of the other production techniques. The impact of the risk factor is more pronounced with a loss of R 262 934 on Farm 4 (see Table 5.32). NPV of Farm 2 remains positive but decreases by over R175 000. Benefit cost ratios indicate that Farm 1, Farm 2 and Farm 3 will still generate benefits that are greater than costs as indicated by BCR ratio that is greater than one. For Farm 4, BCR is less than one indicating that a 10 percent decrease in price will result in costs outweighing benefits for the two production techniques. Farm 2 and Farm 3 still have IRR that is above the cost of capital (8 percent). In the event that trout prices fall, production with two of the four techniques becomes financially unattractive as indicated by negative IRR. One farmer indicated that although rainbow trout prices are increasing, the prices are under threat from imports that are finding their way into the country, an issue that has to be seriously looked into if farmers are to be helped to adopt cleaner production techniques.

### 5.11 Summary

The study revealed that small scale rainbow trout farmers should consider using 'clean' production techniques to ensure long term sustainability of aquaculture production in dams. The alternative production techniques have different capacity and effectiveness in removing waste. Mechanical techniques such as SIFTS and Lift-up are effective in recovering particulate waste, while the intergrated system is the most effective method of recovering waste as it removes both dissolved and particulate nutrients. A combination of waste minimisation measures with waste recovery techniques will ensure long term environmental sustainability of aquaculture. The three proposed production techniques of recovering waste are all viable as indicated by the positive NPV of all the techniques. The production techniques generate significant benefits for the investors hence investment in aquaculture is financially viable.

If prices of inputs change, rainbow trout production remains viable and the changes do not affect choice of production technique by the farmer. However a decrease in price of rainbow trout will result in fall to negative values of NPV of Farm 1 and Farm 4. Farm 3 using SIFTS production technique and Farm 2 (net cage with Lift-up) remain viable. Although the SIFTS production technique is the second best in terms of nutrient recovery, it generates the highest stream of benefits to the farmer. In choosing the production technique, small scale farmers consider the initial investment costs of the techniques hence their choice of production technique will not only be based upon effectiveness in nutrient removal and highest returns. The net cage system requires low capital for setting up, so it will be difficult for farmers to adopt production techniques that require higher investment costs due to the financial constraints that they face in accessing capital. A net cage with Lift-up system will be the production technique that is likely to be chosen by farmers due to the lower investment costs of the system and compatibility with the net cage system. However the intergrated system provides the most environmentally sustainable option that must be chosen ahead of the SIFTS as it effectively deals with both dissolved and particulate nutrients. If benefits that come from the other two species in the intergrated system are considered, the systems profitability will be closer to the SIFTS system. Intergrated systems are the future of aquaculture as they are economically viable, environmentally sustainable and socially acceptable.

# CHAPTER 6

# HOUSEHOLD RESULTS AND DISCUSSIONS

## 6.1 Introduction

The results of the household survey carried out in farms around Western Cape where there is small scale rainbow trout farming in irrigation dams will be presented in this chapter. The chapter begins by giving a description of household characteristics, then involvement in aquaculture, fish consumption by households and willingness to pay (WTP) for water quality improvement to meet different water use categories. The last section estimates WTP or benefits of improving water quality on a typical agricultural farm in the Western Cape where there is small scale rainbow trout farming.

## 6.2 Description of household characteristics

### 6.2.1 Gender of household heads

Of the 51 households interviewed in the survey conducted, 69 percent of the households were male (35) headed, while 31 percent were female (16) headed.

### 6.2.2 Age of household heads

**Table 6.1: Age distribution of household heads**

| Age | Number of reponses | Percentage (%) |
|---|---|---|
| <20years | 0 | 0 |
| 21-30 | 15 | 29.4 |
| 31-40 | 28 | 54.9 |
| 41-50 | 6 | 11.8 |
| >51years | 2 | 3.9 |

Table 6.1 show the age distribution of household heads in the surveyed area. 29.4 percent of the household heads were in the 20-30 years age group, 54.9 percent in 31-40 years age group, 11.8 percent in the 41- 50 years age group and 3.9 percent were above 51 years. The average age of the household heads was 38 years for male and the 37.5 years for females as summarised in Figure 6.1.

The ANOVA F-test results presented in Figure 6.1 shows a p-value of 0.69 indicating that the mean age of male and female household heads did not differ significantly as the p-value is greater than the significance level of test which is 0.05. The results show that the null hypothesis that age of male and female household heads on farms differ significantly, is rejected.

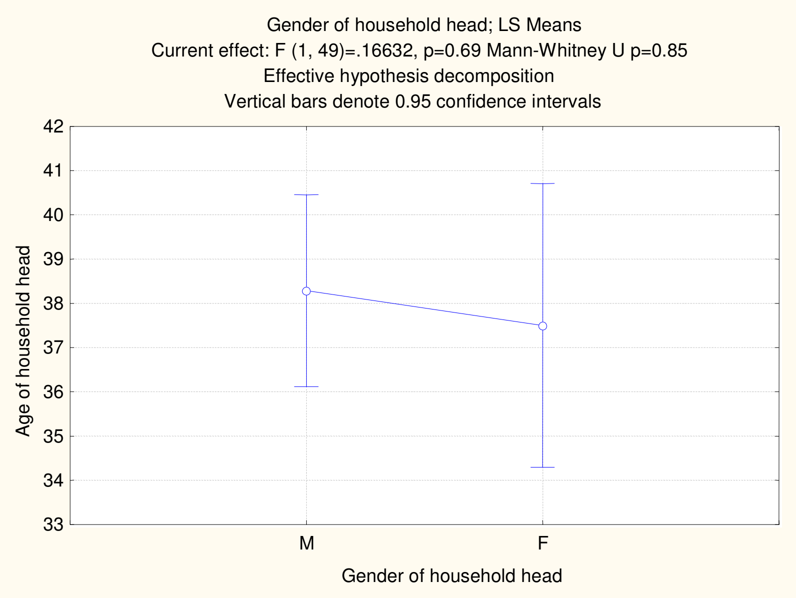



**Figure 6.1: Age and gender of household heads**

### 6.2.3 Education Level

On average, household heads were found to have at least gone to school with 56.9 percent of the household heads indicating that they had attended school up to primary level and 43.1 percent indicating that they had at least attended secondary level and only 11.8 percent had attended grade 10 to grade 12. The highest level of education observed was diploma level and it was at Worcester Forel Project. However, it was noted that all people interviewed involved in aquaculture had attended an intensive hands on aquaculture training course offered by the Division of Aquaculture of Stellenbosch University. The influence that age of household heads had on education level of household heads was found to be significant. A rather strong negative correlation (-0.53) was observed from a regression of education level on age, this signified that older household heads had lower education levels.

### 6.2.4 Household size

The average household size was found to be four members. The largest household unit was seven observed in Goeimoed, while the smallest size of household was a single member household observed in Mountainvinyards. Figure 6.2 indicate that in 84 percent of the households, there were children under the age of 17 years while in 16 percent of the households there were no children under the age of 17 years. On average, there were two children under the age of 17 that were still going to school in households. There was a positive correlation of 0.60 between the household size and children under the age of 17.

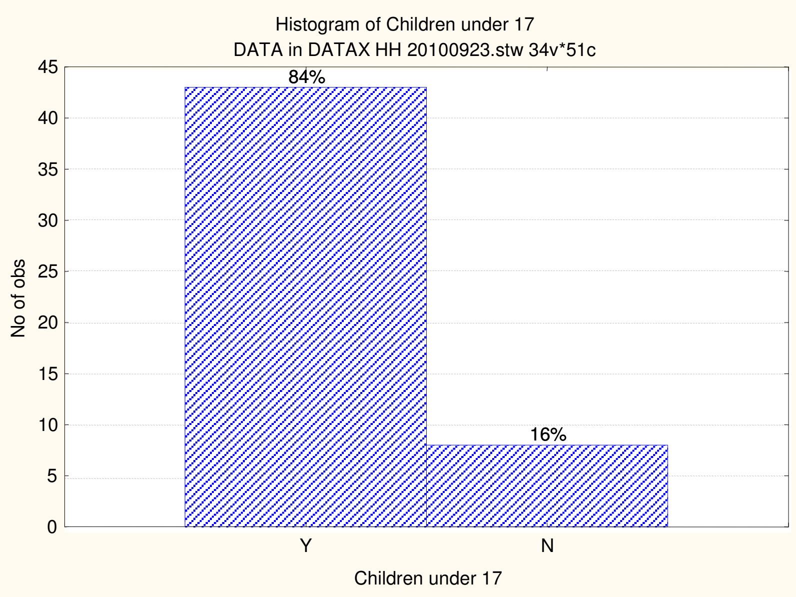



**Figure 6.2: Histogram of children under the age of 17 years**

### 6.2.5 Involvement in aquaculture

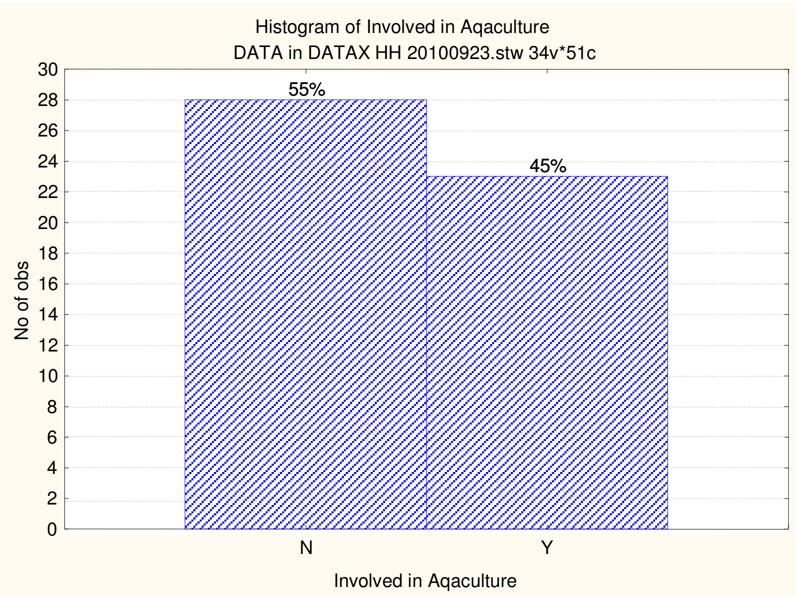



**Figure 6.3: Histograms showing involvement in aquaculture**

The household questionnaire contained a question that asked households if they were involved in aquaculture farming on the farm. 45 percent of the households indicated that they were involved in aquaculture farming while 55 percent of the households were not involved in aquaculture (see Figure 6.3). The aquaculture projects can only accommodate a small number of people and as such on large agricultural farms, a small number of farm workers were involved in aquaculture farming.

To determine whether there was significant difference in age between household heads who were involved in aquaculture and those who were not involved, a Mann-Whitney test was conducted and the results are presented in Figure 6.4.

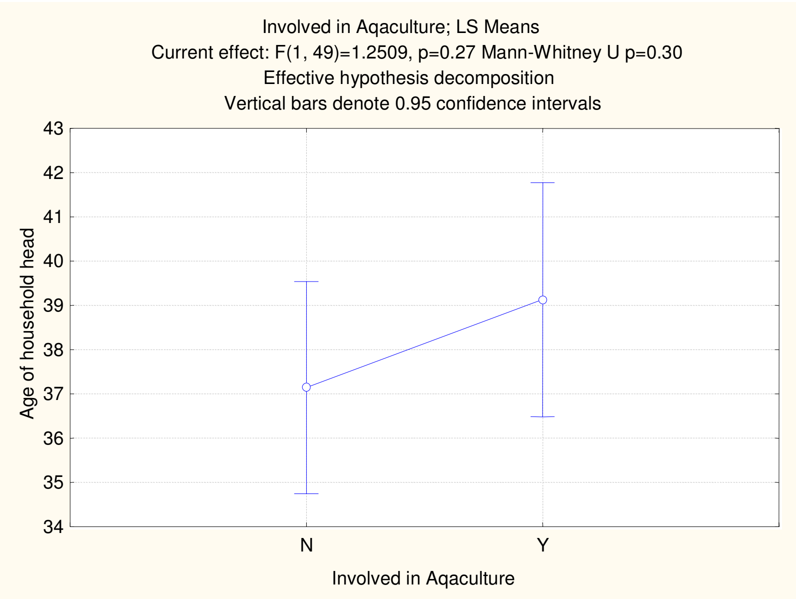



**Figure 6.4: Analysis of age of household head and involvement in aquaculture**

The Mann-Whitney test results show a p-value of 0.30, which is greater than 0.05 showing that the mean age of household heads who were involved in aquaculture farming on the farm was not significantly different from the mean age of household heads who were not involved in aquaculture farming. The null hypothesis that there is a significant difference in age of household heads involved in aquaculture and those not involved is rejected.

## 6.3 Household income

Table 6.2 show the distribution of household income in the study area. 70.6 percent of the households on farms visited earn a monthly income of less than R2 000 per month, 21.6 percent earn household income of between R2 001 and R4 000, and 6.7 percent earn a household income of between R4 001 and R6 000 while 1.9 percent indicated that their household income is between R6 000 and R8 000. The highest observed household income was at Worcestor Forel Project in Worcester.

**Table 6.2: Frequency table of monthly household income**

| More than 8000 | Count | Cummulative count | Percent | Cummulative percent |
|---|---|---|---|---|
| Less than 2000 | 36 | 36 | 70.60% | 70.60% |
| 2001-4000 | 11 | 47 | 21.60% | 92.20% |
| 4001-6000 | 3 | 50 | 5.90% | 98.10% |
| 6001-8000 | 1 | 51 | 1.90% | 100% |
| More than 8000 | 0 | 51 | 0.00% | 100% |

According to Figure 6.5, the Mann-Whitney test results show a p-value of 0.48, indicating that there was no significant difference between mean income of male and female headed households.

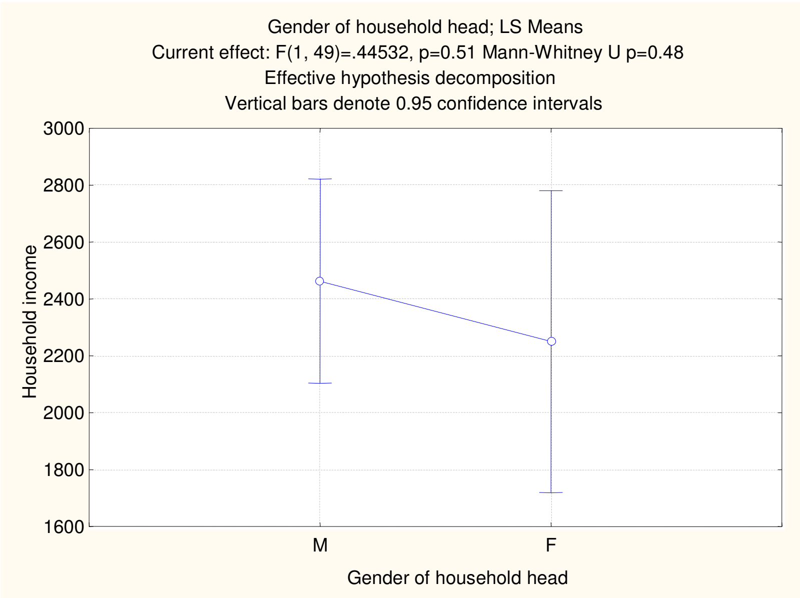



**Figure 6.5: Household income and gender of household head**

However, the graph in Figure 6.5 also indicates that average income for male headed households was slightly higher than for female headed households. This is due to the fact that on most farms women are restricted to "lighter" jobs were renumuneration is lower than men for example at one farm women were mainly working in picking and packing of fruit while men perform a wider range of jobs that included machine operation and other specialised jobs. A weak but positive correlation of 0.363 was noted between the highest level of education of household head and household income. One would have expected a strong correlation but the weak correlation observed can be due to the fact that although most of the household heads had attended school, in farming areas remuneration is mainly based on experience and type of job done. In most cases, type of job perfomed by individuals on farms is based on on-farm training and mentorship, as well as experience. In farming areas, promotion and remuneration is based on experience.

Households who were involved in aquaculture were further asked to indicate their annual income that they obtain from aquaculture and the results are shown in Table 6.3.

**Table 6.3: Frequency table showing annual household income from aquaculture**

| Category | Count | Cumulative count | Percent | Cumulative percent |
|---|---|---|---|---|
| 4000 | 16 | 16 | 69.57 | 69.57 |
| 6000 | 4 | 20 | 17.39 | 86.96 |
| 8000 | 3 | 23 | 13.04 | 100 |

69.6 percent of the households involved in aquaculture, had an annual income from aquaculture of R4 000, 17.39 percent had an annual income of R6 000 and 13.04 percent obtained annual income above R8 000 from aquaculture. It was observed that household income from aquaculture varied from farm to farm. It depends on production performance of the aquaculture farm, number of members involved in aquaculture on the farm as well as other production factors and costs at that particular small scale aquaculture farm.

## 6.4 Fish consumption

On average, households consumed 0.72 kg of fish per week in form of fresh and canned fish. The highest amount of fish consumed per week was 1.5 kg and the lowest amount of fish consumed per week was 250g. Other sources of animal protein consumed by households include chicken, pork, beef and mutton. Chicken was the most popular form of animal protein consumed by households, with households consuming an average of 1.86 kg per week. 84 percent of the households indicated that they consumed mutton, while 62 percent of the households indicated that they consumed beef. The percentage of fish consumed by households as a portion of total animal protein consumed by the household per week was 13 percent.

Households were asked if they had ever consumed fresh fish from the dams. 62.7 percent responded “Yes” while 37.3 percent responded “No” indicating they had never consumed fresh fish from the dam. A Mann-Whitney test was conducted to determine the level of significance of age of household heads and consumption of fresh fish from the irrigation dams and the results are presented in Figure 6.6.

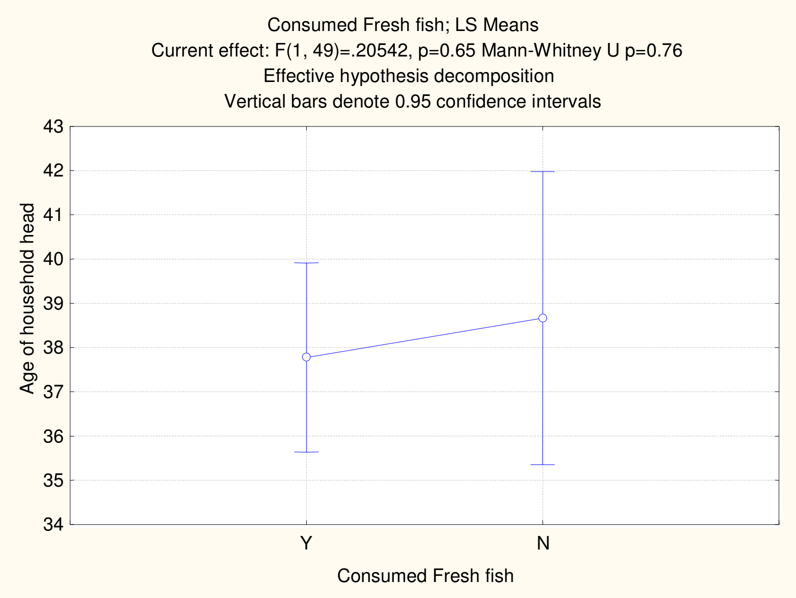



**Figure 6.6: Analysis of age of household head and consumption of fresh fish**

The Mann-Whitney test results in Figure 6.6 show a p-value of 0.76, indicating that there was no significant difference between mean age of household heads who had consumed fresh fish from the irrigation dam and those who had never consumed fresh fish from the irrigation dams. The results show that age did not influence consumption of fresh fish from the irrigation dams. The graph on Figure 6.7 show that there was no significant difference between mean income of household heads who had consumed fresh fish from the irrigation dams and those who had never consumed fresh fish from the irrigation dams.

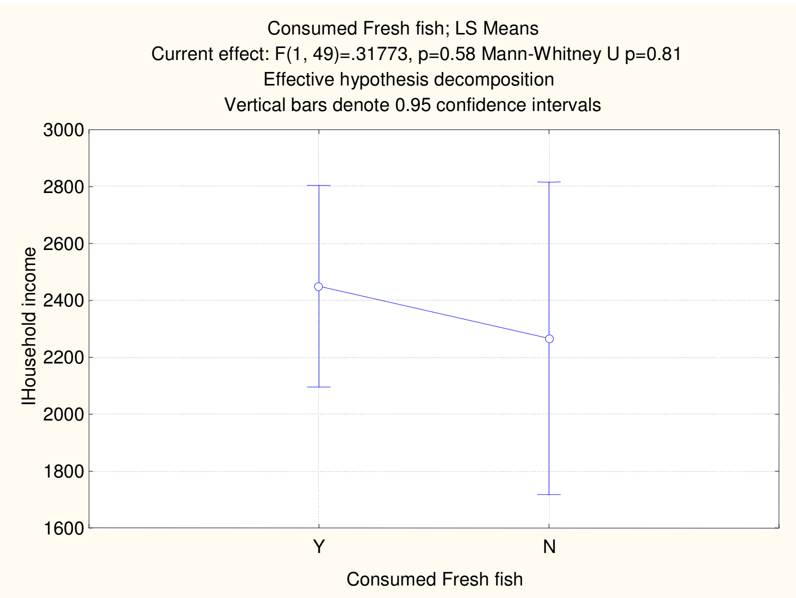



**Figure 6.7: Household income and consumption of fresh fish**

The results show that income is not a factor that can be considered for consumption of fresh fish from the irrigation dams.

A Mann-Whitney test was conducted to establish the relationship between involvement in aquaculture on the farm and the amount of fish consumed by households per week and the results are presented in Figure 6.8. The results show a p-value of 0.01, which is less than 0.05, showing that there was a siginificant difference between the average amount of fish consumed by households involved in aquaculture and households that where not involved in aquaculture.

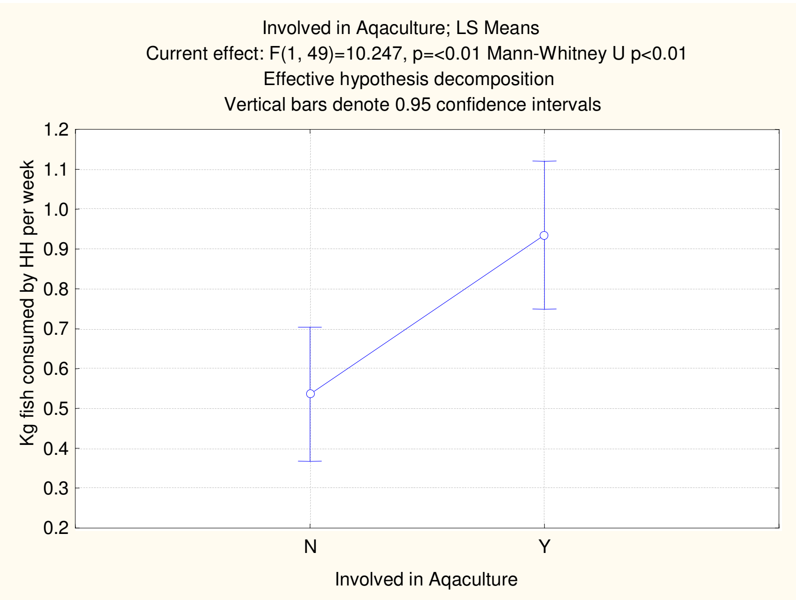



**Figure 6.8: Amount of fish consumed by household and involvement in aquaculture**

In this case the null hypothesis is accepted as the results show that there is a significant difference between the average amount of fish consumed by households involved in aquaculture and average amount of fish consumed by households who were not involved in aquaculture.

Table 6.4 below show that on average, households that were involved in aquaculture farming consumed more fish than households that were not involved in aquaculture farming.

**Table 6.4: Frequency table showing involvement in aquaculture and fish consumption**

| | Response | No of responses | kg of fish consumed by Household per week (mean) |
|---|---|---|---|
| Involved in aquaculture | N | 28 | 0.536 |
| Involved in aquaculture | Y | 23 | 0.935 |
| Total | | 51 | 0.716 |

The results indicate that involvement in aquaculture influences fish consumption. However, although involvement in aquaculture did show that it significantly influence fish consumption by households, it was noted that most of the fish produced from aquaculture on the farms was for commercial purposes and was supplied to a fish processing company.

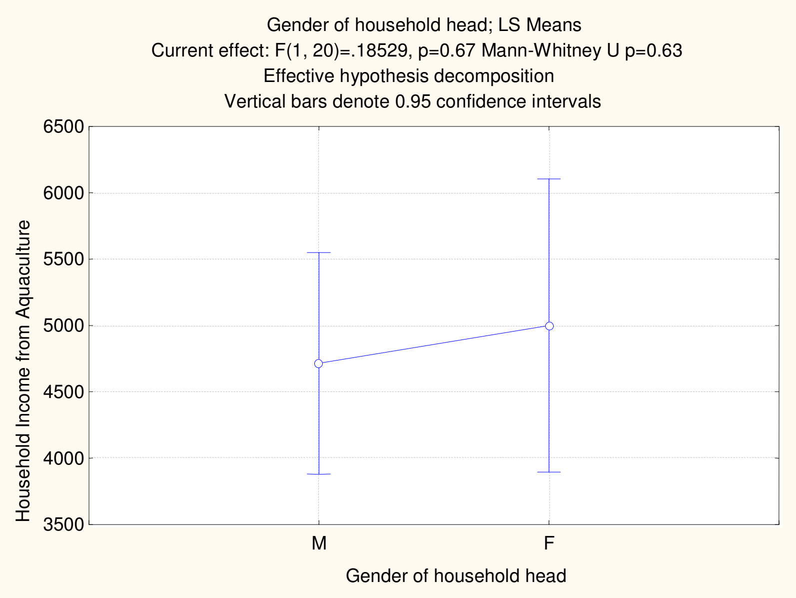



**Figure 6.9: Household income from aquaculture and gender of household head**

Figure 6.9 show the results of the Mann-Whitney test conducted and a p-value of 0.63 indicate that there was no significant difference between mean income from aquaculture for male headed households and female headed households involved in aquaculture farming. This was due to the fact that at most of the aquaculture farms, income from aquaculture farming is shared equally amongst the members at the end of each fish production season.

### 6.4.1 Fish eating habits

When households were asked if the start of aquaculture on the farm had changed their fish eating habits, 43 percent of the responses where in affirmative while 57 percent indicated that introduction of aquaculture did not change their fish eating habits. The Mann-Whitney test results presented in Figure 6.10, show a p-value of 0.01 (that is less than the significance level of 0.05) indicating that there was a significant difference between the mean amount of fish consumed by households who indicated that there have been a change in fish eating habits since the aquaculture project was started and those who indicated that there were no changes. The results suggest that the start of small scale aquaculture farming might have caused a significant change in amount of fish consumed by households per week.

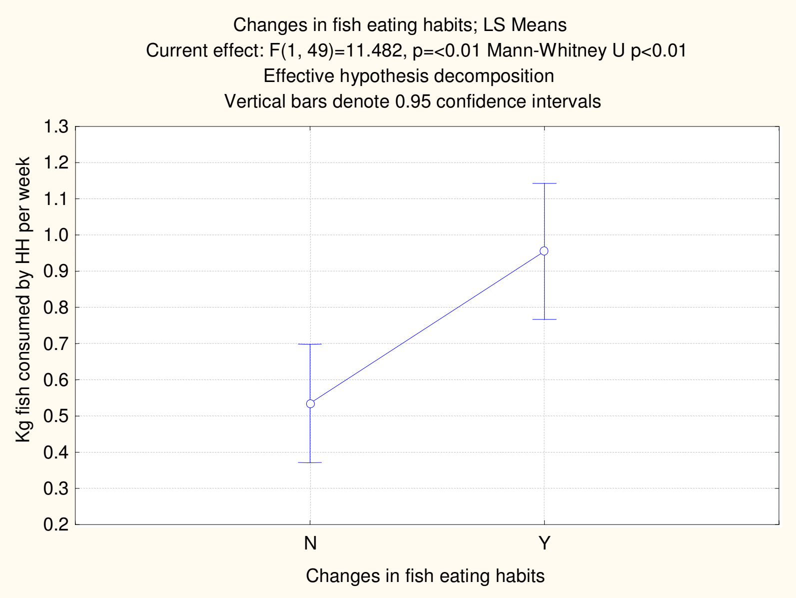



**Figure 6.10: Amount of fish consumed and changes in fish eating habits**

The graph also show that households who indicated that there was a change in fish eating habits were consuming an average of 0.95 kg of fish per week, while those who indicated that their fish eating habits have not changed consumed 0.53 kg per week. The reason for the difference might be that the start of small scale aquaculture farming increased availability of fish as an alternative source of animal protein to households because fish that failed to meet the grade required for processing was sold locally.

## 6.5 Maintenance of water quality

Water from the dams used for aquaculture is mainly used for irrigation of wine grapes and fruit trees. In Worcester, where aquaculture operations are on a municipal dam, the water is mainly used for irrigation of a golf course. Poor water quality negatively affects growth rate of fish and also causes outbreak of diseases and as such maintenance of good water quality should be a top priority for the aquaculture farmer. When households were asked about the importance of maintaining water quality, 98 percent of the households' acknowleged the importance of maintaining good water quality in irrigation dams and 2 percent were of the opinion that it was not important. On 40 percent of the dams, households indicated that water from the dams is sometimes used for domestic purposes, fish production and recreational fishing.

Households were further asked to rate the suitability of water from the dams for irrigation, fish production (recreational fishing & aquaculture), swimming and domestic purposes (washing & bathing). Table 6.5 show the responses of households when they were asked to rate the suitability of water from the dams for the mentioned uses.

**Table 6.5: Frequency table showing rating of water suitability for different use categories**

| | 1-Dangerous | | 2-Not acceptable | | 3-Acceptable | | 4-Good | |
|---|---|---|---|---|---|---|---|---|
| | No. of response | % of total response | No. of responses | % of total response | No. of response | % of total response | No. of response | % of total response |
| Domestic Purposes(bathing & washing clothes) | 1 | 2% | 38 | 74.5% | 12 | 23.5% | 0 | 0% |
| Irrigation | 0 | 0% | 0 | 0% | 21 | 41.2% | 30 | 58.8% |
| Fish production | 0 | 0% | 0 | 0% | 29 | 56.9% | 22 | 43.1% |
| Swimming | 0 | 0% | 10 | 19.6% | 38 | 74.5% | 3 | 5.9% |
| Livestock | 0 | 0% | 0 | 0% | 36 | 70.6% | 15 | 29.4% |

Two percent rated water from the dam as dangerous to use for domestic purposes (washing & bathing), 74.5 percent rated the water as not acceptable for domestic purposes while 23.5 percent rated the dam water as acceptable for use for the mentioned domestic purposes. On rating suitability of dam water for irrigation purposes, 41.2 percent gave the dam water a score of '3' indicating that the water quality is acceptable for irrigation purposes and 58.8 percent gave a rating of '4' showing that the water is good for irrigation. From the responses, it can be concluded that aquaculture activities in the dams have not yet affected the quality of water for irrigation.

All households indicated that water from the dams was suitable for fish production with 56.9 percent rating the water as acceptable while 43.1 percent rated the water as good. Households were further asked to rate suitability of water quality in the dam for swimming (getting in contact with the dam water) and 19.6 percent gave dam water a rating of '2' that is it is not acceptable, while 74.5 percent gave a rating of '3' indicating that the water quality was acceptable and 5.9 percent indicating that it was good. The ratings indicate that households had a good understanding on suitability of water quality for the different water use categories as more people gave a high rating for water uses that require comparatively lower quality than other uses.

### 6.6 Willingness to pay for water quality improvement

When households were asked if they were willing to pay for pollution control programmes that would improve water quality in farm dams, 45.1 percent of the households were willing to pay (WTP) and 54.9 percent were not willing to pay (see Table 6.6).

**Table 6.6: Table showing percentage of households willing to pay for water quality improvement**

| Category | Count | Cumulative count | Percent | Cumulative percent |
|---|---|---|---|---|
| Yes | 23 | 21 | 45.1 | 45.1 |
| No | 28 | 51 | 54.9 | 100 |

Households who had indicated that they were willing to pay, were then further asked to state the amounts of money that they would be willing to pay in order to improve water quality from one use category to another. The first water quality improvement they were asked was willingness to pay for water improvement from a state where there was eutrophication (as indicated in pictures provided, see Appendix 3) to a state suitable for irrigation and fish production. The mean WTP for improving water to a state suitable for irrigation was R40 per year as shown in Table 6.7.

**Table 6.7: Frequency table of willingness to pay for improving water quality to a condition suitable for irrigation and fish production**

| | | **Number** | **Mean WTP (irrigation) (R)** |
|---|---|---|---|
| Gender of household head | Male | 35 | 37.43 |
| Gender of household head | Female | 16 | 45.63 |
| Total | | 51 | 40 |

Table 6.7 also indicate that female headed were willing to pay more on average than male headed households. Female headed households were willing to pay an average of R45.63 per year for improvement of water quality to a state suitable for fish production and irrigation. The lowest amount that households were willing to pay was R0 per year while the highest amount was R160, while the mode was R90.

A follow up question was included in the questionnaire to get reasons why households who had indicated that they were not willing to pay for water quality improvement in dams. Some respondents indicated that they were not willing to pay because they do not have money to spare from their incomes to pay for water quality improvements. Some were of the opinion that people involved in activities that cause pollution should try and reduce pollution or pay for the clean up measures that might be required to improve water quality. One respondent indicated that “it is the responsibility of the farmer to ensure that all activities that have a potential to cause pollution of water on the farm put measures in place to reduce effluent released into the dam water”. He went on to give examples of waste coming from dairy, wine production where there were measures in place to ensure that effluent is reduced before water is allowed back into the river stream in other cases the water is not even allowed back into the river but treated and reused for other purposes. Another respondent indicated that waste added from aquaculture farm into water in the municipal dam infact had an advantage as nutrients added had a positive benefit to irrigation of the golf course which is the main use of water from that dam.

Based on the ANOVA F-test conducted and results presented in Figure 6.11 and Table 6.8, there was a significant difference between the mean WTP for improvement of water to a state suitable for irrigation for households involved in aquaculture and mean WTP for water quality improvement to a state suitable for fish production for households who were not involved in aquaculture.

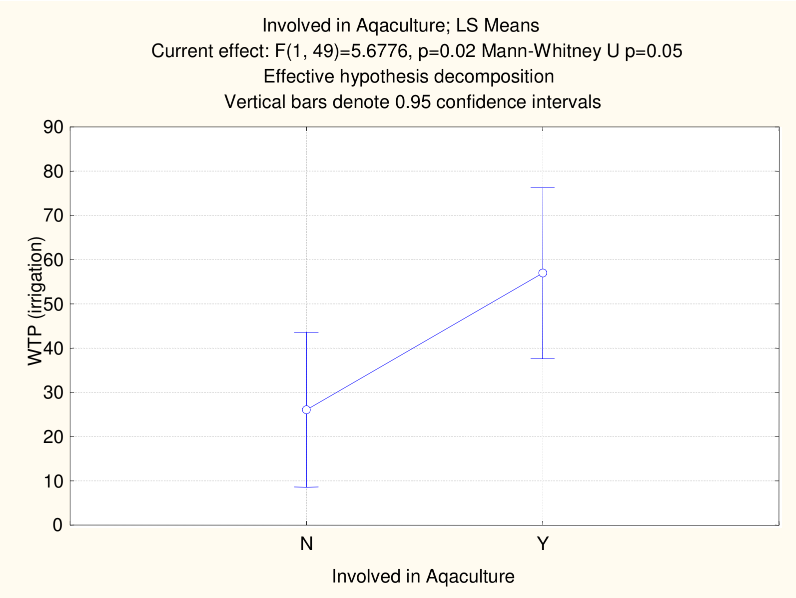



**Figure 6.11: Willingness to pay to improve water quality to a state suitable for irrigation and involvement in aquaculture**

From Table 6.8, on average WTP of households involved in aquaculture was R56.96 which was higher than the average WTP for households who were not involved in aquaculture of R26.07. The results indicated that households involved in aquaculture were willing to pay more for improvement of water quality. This could be due to their perceptions that water quality improvement could give them more benefits in aquaculture and also that they will be working in cleaner water. Results of the Spearman correlation analysis of household income from aquaculture and WTP for improvement of water quality to a state suitable for irrigation gave a p-value of 0.08 showing that there was no significant correlation between the two variables.

**Table 6.8: Frequency table showing willingness to pay to improve water quality to a state suitable for irrigation and involvement in aquaculture**

| | | **Number** | **Mean WTP (Irrigation) (R)** |
|---|---|---|---|
| Involved in aquaculture | No | 28 | 26.06 |
| Involved in aquaculture | Yes | 23 | 56.97 |
| Total | | 51 | 40 |

Households who were involved in aquaculture were willing to pay more for water quality improvement programmes that would improve the state of water quality to a condition suitable for both irrigation and fish production. The results confirm that households involved in aquaculture had a better understanding of the importance of maintaining good water quality for fish production and irrigation as they benefited from aquaculture.

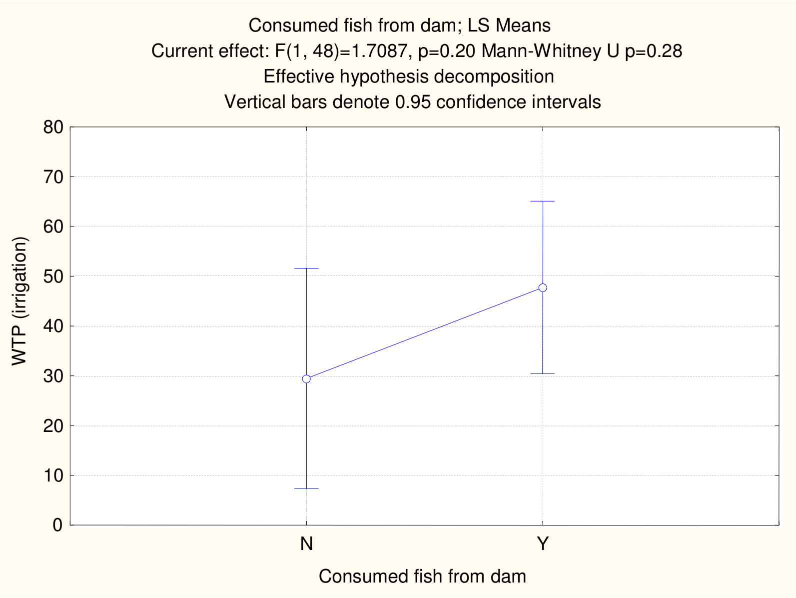



**Figure 6.12: Willingness to pay for improvement of water to a state suitable for irrigation and consumption of fish from the dam**

Results of the Mann-Whitney test in Figure 6.12 show that there was no significant difference between mean WTP for improvement of water to a state suitable for irrigation for households who had consumed fish from the dam and those who had never consumed fish from the dam. This could be due to the fact that at most of the small scale farms, dam water quality have not yet been degraded to a state where people would be concerned of the quality of fish produced from the dams. However, Table 6.9 also shows that households who had consumed fish from the dams were willing to pay an average of R47.74 per year to improve water quality while those who had never consumed fish from the dams used for aquaculture were willing to pay R29.47.

**Table 6.9: Frequency table showing WTP for improvement of water to a state suitable for irrigation and consumption of fish from the dam**

| | | Number | Mean WTP (irrigation) (R) |
|---|---|---|---|
| Consumed fish from the dam | No | 20 | 29.47 |
| Consumed fish from the dam | Yes | 31 | 47.74 |
| Total | | 51 | 40.8 |

Households were further asked their WTP for water quality changes that will improve water quality from a state suitable for irrigation and fish production to a state suitable for swimming and the results of Mann-Whitney test conducted are shown in Figure 6.13.

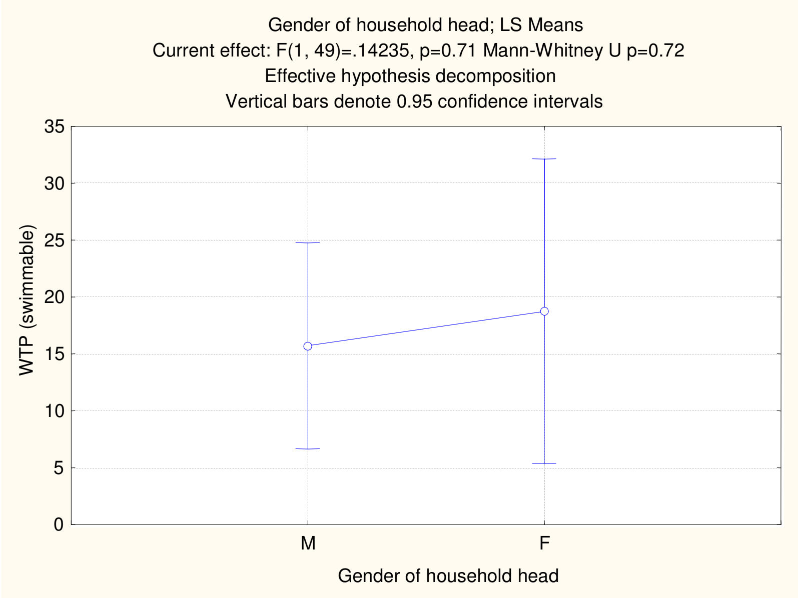



**Figure 6.13: Analysis of WTP for improvement of water to a state suitable for swimming and gender of household head**

Figure 6.13 show the results of the Mann-Whitney test carried out and a p-value of 0.72 indicating that there was no significant difference between mean willingness to pay for water quality improvement from a state suitable for irrigation to a state suitable for swimming (coming into contact with water) among the gender groups. However the mean for willingness to pay for improvement of water quality to a state suitable for swimming for female headed households (R18.8) was slightly higher than for male headed households (R15.71) (see Table 6.10). On average households were willing to pay R16.67 annually for improvement of water from a state suitable for irrigation to a state suitable for swimming.

**Table 6.10: WTP for improvement of water to a state suitable for swimming and gender of household head**

| | | Number | Mean WTP (Swimmable) (R) |
|---|---|---|---|
| Gender of household head | Male | 35 | 15.71 |
| Gender of household head | Female | 16 | 18.75 |
| Total | | 51 | 16.67 |

Figure 6.14 show results of the Whitney-Mann test indicating a p-value of 0.01. The results indicate that there was a significant difference between the mean WTP for improvement of water from a state suitable for irrigation and aquaculture to a state suitable for swimming for households involved in aquaculture and those who were not involved in aquaculture.

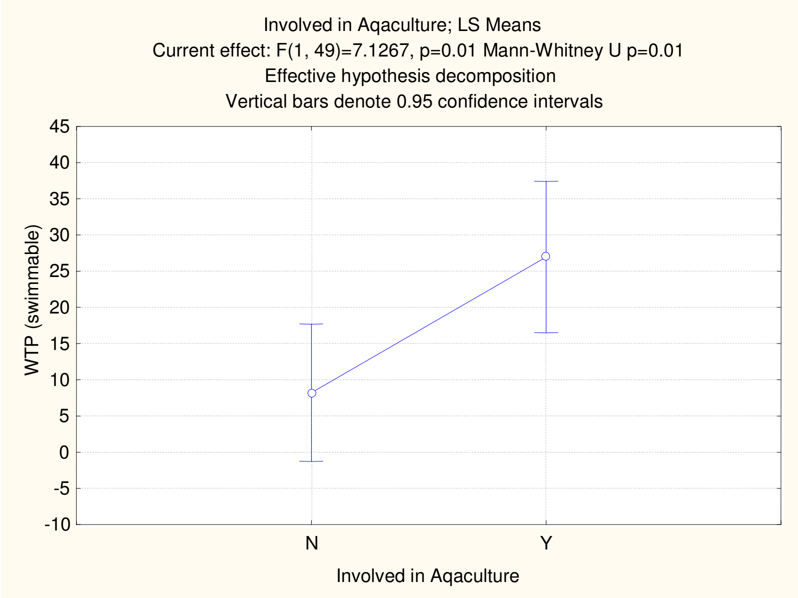



**Figure 6.14: Analysis of WTP to improve water quality to a state suitable for swimming and involvement in aquaculture**

Households involved in aquaculture were willing to pay R26.96 (see Table 6.11) as compared to the mean of R8.21 for households not involved in aquaculture. The difference in the average amounts that households involved in aquaculture and households not involved in aquaculture were willing to pay for improvement of water quality to a state suitable for swimming may be due to the fact that people involved in aquaculture were willing to pay more because they get in contact with the dam water on daily basis when they carry out their routine activities in fish production as well as when they carry out cage maintenance and net repairs.

**Table 6.11: WTP for improvement of water quality to a state suitable for swimming and involvement in aquaculture**

| | | Number | Mean WTP (Swimmable) (R) |
|---|---|---|---|
| Involved in aquaculture | No | 28 | 8.21 |
| Involved in aquaculture | Yes | 23 | 26.96 |
| Total | | 51 | 16.67 |

Households were further asked for their WTP for improvement of water quality from a state suitable for swimming to a state suitable for domestic purposes such as washing clothes and bathing. The results of the Mann-Whitney test results on Figure 6.15 show a p-value of 0.89 indicating that there was no significant difference between mean willingness to pay for improvement of water quality to a state suitable for domestic purposes for male and female headed households.

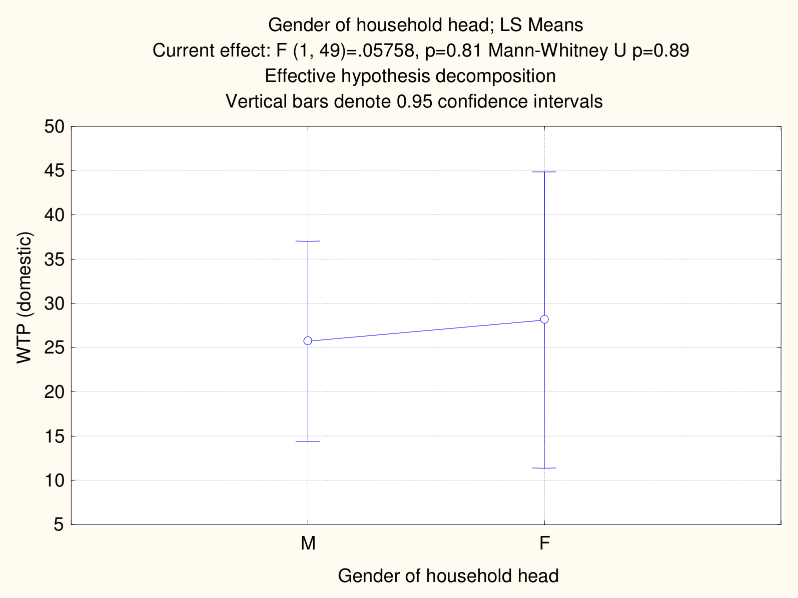



**Figure 6.15: Analysis of WTP for water improvement to a state suitable for domestic purposes and gender of household head**

However Table 6.12 also indicate that on average female headed households were willing to pay slightly more than male headed households, with female headed households willing to pay an average of R28.13 and male headed households willing to pay R25.71. This may be due to the fact that in most cases women do most of the domestic chores where water is used and would prefer a better water quality that will be used for domestic purposes.

**Table 6.12: WTP for improvement of water quality to state suitable for domestic purpose and gender**

| | | Number | Mean WTP (Domestic purposes) (R) |
|---|---|---|---|
| Gender of household head | Male | 35 | 25.71 |
| Gender of household head | Female | 16 | 28.13 |
| Total | | 51 | 26.47 |

## 6.7 Average willingness to pay for different water use categories

Following Hanemann's procedure, maximum willingness to pay for the average household on the farms was estimated using the mean (Hanemann, 1985). Table 6.13 show the estimated mean benefits (WTP) by level of water quality improvement. The results in Table 6.13 indicate that it was very important for the community to maintain water quality that is good for irrigation and fish production because these were the two main water uses of water from the dam on such farms as indicated by the WTP of R40 per annum.

**Table 6.13: Average WTP for water quality improvement to meet different water use categories**

| Levels of water quality improvement | Average WTP per annum (R) |
|---|---|
| WTP (improve water quality to a state suitable for irrigation & fish production) | 40.00 |
| WTP (improve water quality to a state suitable for swimming) | 16.67 |
| WTP (improve water quality to a state suitable for domestic purposes e.g. washing, bathing etc.) | 26.47 |

The results also indicate that the community also attached a high value for improvement of water quality from a state suitable for swimming to a state suitable for domestic purposes (R26.47) than from a state suitable for irrigation to a state suitable for swimming (R16.67) because water used for domestic purposes should be of higher quality than water used for swimming. However, the results indicate that the respondents were inconsistent with their WTP on the three water quality improvement categories. If their choices were consistent, households would have been willing to pay a higher amount for water quality improvement that will make the dam water suitable for domestic purposes than for irrigation purposes as domestic purposes require water of higher quality than irrigation. The results indicate that households made irrational choices on water quality improvement for irrigation and fish production compared to WTP for domestic uses. The choices by the households might have been influenced by the fact that the water from the dams is mainly used for irrigation and water used for domestic purposes at most farms is treated before they use it for domestic purposes.

The averages calculated and presented in Table 6.14 were then estimated for a typical agricultural farm in the Western Cape. Assuming that there are 30 households staying on an agricultural farm and each household comprising of four people the total number of people staying on the farm will be 120. The total willingness to pay based on the estimated number of households on the farm could then be as presented in Table 6.14.

**Table 6.14: Estimated total WTP on a typical farm where there is small scale aquaculture farm**

| | Average WTP per annum (R) | Total WTP per annum (R) |
|---|---|---|
| WTP(improve water quality to a state suitable for irrigation & fish production) | 40 | 1200.00 |
| WTP(improve water quality to a state suitable for swimming) | 16.67 | 500.10 |
| WTP (improve water quality to a state suitable for domestic purposes e.g. washing, bathing e.t.c.) | 26.47 | 794.10 |

In order to maintain water quality that is suitable for irrigation and fish production, the community would be willing to contribute R1 200 per annum towards pollution control programs in dams. The estimated WTP indicate that households staying on farms attach a value to dam water quality and they would be willing to pay to ensure that water quality is maintained in the dam for both irrigation and aquaculture activities. The results also show that in addition to the financial benefits that small scale trout farmers obtain from using clean production techniques, households staying on the farms are also set to benefit from the maintenance of good water quality.

## 6.8 Summary

The results of the household survey indicated that small scale aquaculture farming projects on farms involve men and women. The results also show that average WTP of people involved in aquaculture was significantly higher than WTP of people not involved in aquaculture. Householdss were willing to pay on average more for improvement of water quality to a condition suitable for irrigation and fish production than the other two water quality improvements categories. The results indicate that in addition to the financial benefits that small scale rainbow trout farmers get from using “clean” production techniques, the community will also benefit significantly as reflected by the willingness to pay for dam water quality improvements.

# CHAPTER 7

# CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

Aquaculture could be seen as favourable to the rapidly growing global aquaculture industry but now there are major emerging social and environmental challenges to be met by the industry. The emerging issues are guided by the principles of natural capital, sustainability, ecological intergrity and environmental stewardship (Phillips & Silva, 2007). The challenges that are faced by farmers in reducing environmental impacts of aquaculture farms could also open an opportunity for farmers to adopt cleaner aquaculture production techniques that will better position farmers in a strongly regulated industry and environmentally conscious consumer.

The first objective of this study was to describe the structure of the aquaculture industry. It was observed that South Africa has an established marine and freshwater aquaculture industry that has rapidly expanded in the past ten years and fast growth is also expected in the industry in future. The aquaculture industry comprises of large scale and small scale aquaculture farmers. In most cases, large scale farms are privately owned and produce high value species for both domestic and international markets. Small scale aquaculture farms produce for food security purposes but recent trends show that there is an increase in number of small scale aquaculture farms that are producing fish for commercial purposes. The increase in small scale aquaculture commercial farms can be attributed to lessons learnt from the past where small scale farms that were established for food security purposes, failed, as aquaculture is a capital intensive operation where production from small scale farms should be market driven in order for the small scale farms to be sustainable (Rouhan & Britz, 2004). One such example are small scale farms that were visited in this study that operate under the Hands-On Fish Farmers Cooperative that are producing rainbow trout for the processing industry in farm dams. It was observed that the main pull-factors in growth of aquaculture industry is the high demand of fish products due to population growth, growth in the economy of South Africa and changing consumer preferences due to health awareness and access to international markets. While push-factors include availability of suitable water resources, desire to maximise income from available resources, employment creation, good infrastructure and suitable climatic conditions.

However prospective investors will have to face the tight environmental regulatory framework in aquaculture in South Africa. Issues of environmental sustainability in aquaculture are well covered in the legislation. The legislative framework in South Africa requires that aquaculture producers reduce their ecological foot print. It can be concluded that South Africa has progressive aquaculture legislation that could drive aquaculture towards environmental sustainability. The formation of the Department of Water and Environmental Affairs as the main department regulating aquaculture developments and Department of Agriculture Forestry also playing a part in aquaculture development together with local governments will help in future environmental regulation of aquaculture. Recent trends in markets indicate that governments are no longer the only regulatory authority that the aquaculture producer have to pay attention to, as the market also now plays an important role in ensuring that aquaculture producers use environmentally responsible practices. Increasing environmental awareness of consumers requires aquaculture producers to adopt 'clean' production techniques in aquaculture if their products are to be accepted in the market. Aquaculture production practices must lead to a product safe for human consumption by domestic and foreign consumers.

Continued expansion of aquaculture will require adoption of production techniques that reduces the ecological foot print of aquaculture. There are a number of production techniques that have been tried for water based aquaculture but a few have been successfully developed for use at a larger scale. Some of the techniques have been rendered impractical for implementation at commercial farms but the main factor that determines adoption of cleaner production techniques is the economics of the production techniques. Adoption of production techniques will only occur under conducive economic conditions and farmers will only adopt production techniques that will enable them to increase their income and at the same time reducing environmental impacts.

It was also observed that significant reductions in waste can be achieved through employing best management practices. The aim of a fish farmer should always be to ensure that fish consume and utilise much of the feed that is added into system with very little feed lost as waste. Proper planning for aquaculture activities is required in order to reduce waste in aquaculture. Sites chosen for aquaculture should be thoroughly investigated before setting up aquaculture farms. The use of models on expected nutrient loading together with investigations on the capacity of water bodies to naturally degrade waste will result in choice of sites that are suitable for aquaculture. Choosing suitable sites help in averting environmental problems as well as reducing losses to the farmers due to self pollution of aquaculture farms. Management on the farm focusing on all aspects of feed that include quality of feeds, digestibility of feeds, ingredients, handling, distribution, and storage is very important in reducing waste on an aquaculture farm. Farmers can also employ methods that enhance natural degradation of waste such as placing screening devices or reefs beneath the net cages. If the above mentioned strategies are employed together with production techniques that ensure waste recovery, then long term sustainability of small scale rainbow trout production in irrigation dams will be achieved.

The economic analysis carried out in this study revealed that investment in aquaculture will give high returns to the fish producer regardless of the production technique chosen from the three alternatives compared in this study. The identified production techniques that can be transferred and adopted by small scale farmers include the use of a net cage with a Lift-up dead fish and waste collector, semi-intensive floating tank system (SIFTS) and intergrated closed bag system. The three identified production techniques provide farmers with options to move to ‘cleaner’ production system at the same time improving profitability of their farms. In this study, key factors which determine the commercial potential of the alternative production techniques were highlighted and the benefits of using ‘cleaner’ production techniques were also indicated. The results of the nutrient loading analysis show that the most effective production technique that reduces effluent loading from water based aquaculture system is the intergrated system. The use of fed fish and extractive organisms results in zero effluent and nutrient emissions from aquaculture. The results also indicated that use of production techniques that have mechanical systems recollecting waste are also effective ways of reducing environmental impacts with the SIFTS technique being the better system for mechanical recovery of waste. However, the use of a Lift-up system is important for small scale freshwater aquaculture in the Western Cape as it reduces solid waste accumulation and it is also compatible with cage infrastructure that is already being used by the small scale farmers.

The regulatory environment of aquaculture in South Africa requires the farmers to adopt ‘clean’ production techniques hence farmers will have to consider intergrated systems as the best alternative for future aquaculture development so as to avoid penalties that will be imposed on effluent emissions in future. Nutrient recycling ability of the intergrated system will ensure long term sustainability of small scale aquaculture in irrigation dams. Although waste recovery is the core benefit of intergrated aquaculture systems, the increase of production, more diverse and secure business and large profits should not be underestimated as additional advantages. However, the use of intergrated system is still a long way, as more research is still required to further investigate the identified candidate species that are most suited to the South African conditions and the technical implementation of intergrated farms. Further research and trials need to be conducted of intergrating trout with either indigenous species like mullet and investigate suitable macroalgae or vegetables that can be used in freshwater systems. It is also important to investigate other imported species such as catfish and freshwater mussels as options for the system considering the regulatory framework of importation of fish species for aquaculture. It will also be important to facilitate commercialization and promote effective legislation for the support and inclusion of intergrated aquaculture through providing incentives especially considering the environmental benefits of intergrated aquaculture over monoculture.

The results of the financial analysis carried out, indicate that the most effective production technique to deal with waste from aquaculture is not necessarily the production technique that produces best returns to the farmer. The intergrated system might be the most efficient for waste removal, but the SIFTS system is the production technique that gives the farmer the highest returns on investment. The huge initial investment costs of intergrated closed bag system and SIFTS makes it difficult for small scale farmers to adopt the production techniques and farmers are more likely to continue using net cages. Lack of investment capital is one area that is still yet to be addressed for small scale aquaculture farmers as they cannot access finance from banking institutions as aquculture is perceived as a high risk venture and lack of collateral.

Farmers will more likely adopt net cage with Lift-up system due to its lower cost and compatibility with the net cage system. Since fish farmers are facing high costs of feed, a combination of good feed management practices and waste recovery using a Lift-up system can improve economic viability and environmental sustainability of small scale trout farms. Combining good feed management practices with recovery of waste will ensure long term sustainability of small scale rainbow trout farming in irrigation dams.

Most of the environmental and social benefits that arise from removing waste produced from aquaculture from farm dams were not reflected in the financial analysis. The results of the household questionnaire information collected using the contingent valuation method show that removing of organic waste in farm dams will generate a significant amount of benefits to the farm community. Households indicated that they were willing to pay for water quality improvements that will result in maintanence of water quality that is suitable for both irrigation and aquaculture. Households involved in aquaculture were willing to pay significantly higher amounts to maintain water quality state that is suitable for irrigation and fish production. The average willingness to pay for improving water quality to a state suitable for fish production was found to be R40 per person per year. The WTP revealed by householdss indicate that the community attach value to good water quality in farm dams. It also indicate that aquaculture is making a significant contribution to the community as indicated by the WTP for water improvement that will ensure continuation of aquaculture production on the farm at the same time maintaining water quality suitable for irrigation. It can be concluded that removal of waste falling of from fish farms will generate significant benefits for both the fish farmer and the community at large.

## 7.2 Recommendations

This study highlighted the possibility of using production techniques that reduces environmental impacts of aquaculture, but further research is required on the use of the techniques in South Africa.

Implementing trials of the identified production techniques will be very important in assessing whether the techniques can be adopted by the small scale farmers. Further research in implementation of intergrated aquaculture systems is also required. This will help in developing intergrated systems based on biological relationships and ability of the cultured species to utilise feeds at different levels so as to come up with a system that can be adopted by the farmers. Some of the proposed production techniques require huge initial investment and costs and there is need to further investigate the best way in which the state can possibly intervene to help the small scale farmers to adopt the capital intensive but environmentally friendly techniques such as SIFTS.

## REFERENCES


Ackerfors, H. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. Journal of Applied Ichthyology. 10: 225–41

Ackefors, H. 1997. Environmental impact of different farming technologies. In Svennevig N., Reinertsen H., New M. (Ed.), Proceedings of the second international symposium on sustainable aquaculture, Oslo, Norway 2-5 November 1997.

Ackerfors, H and Olburs, C.H. 1995. Aquaculture: A threat to the environment, or opportunities for a new industry? The Sweedish paradox. Journal of Marine Biotechnology. 3: 53-55.

AquAgris. 2009. D19: Report on Exciting advances in fisheries management and the design of aquaculture systems, and the realisation of ETAP objectives, Workshop Bremen, 9th of February 2008

Aquanutro. 2010. Aquanutro Fish nutrition. www.aquanutro.co.za [accessed on 27 March 2010]

Angel, L.D. and Spanier, 2002. An application of artificial reefs to reduce organic enrichment

caused by net-cage fish farming: preliminary results. ICES Journal of Marine Science 59: 000–000. 2002, available online at http://www.idealibrary.com [accessed on 23 March 2010]

Annonymous source. 2010. A description of mitigation measures (safeguards and contingency plans where relevant) to be undertaken to help prevent or reduce the actual or potential effect: Application for Mellville Cove Port Gore Coastal Permit 2010.

Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R. and Schuman, H. 1993. Report on NOAA panel on Contingent Valuation. Federal Register, January 15, 58(10):4601-4614

Baird, D.J., Beveridge, M.C.M., Kelly, LA., Muir, J.F. 1996. Aquaculture and water resource management, Blackwell science, Oxford, UK.

Barbato, F., De Angelis, N. and Ciattaglia, A. 2004. CA.WA.CO.RE. Cage Waste Collection and Recovery Device. Rome, Italy.

Barrington, K., Ridler, N., Chopin, T., Robinson, S., Robinson, B., 2008. Social aspects of the sustainability of integrated multi-trophic aquaculture. Aquaculture International.

Bergheim, A. 2007. Global aquaculture water use and pollution; Aquaculture Engineering and Environment; Trivandrum: Research Signpost.

Bergheim, A. and Brinker, T. 2003. Effluent treatment for flow through systems and European Environmental Regulations. Aquaculture Engineering Journal, 27.

Bergheim, A. and Forsberg, O. 1993. Attempts to reduce effluent loadings from salmon farms by varying feeding frequencies and mechanical effluent treatment. European Aquaculture Society, Special Publication No. 18.

Beveridge, M.C.M. 1984. Cage and pen fish farming: carrying capacity model and environmental impact. FAO fish technical paper, 255.

Beveridge, M.C.M. 1996. Cage Aquaculture, (2$^{nd}$ edition). Fishing News Books, Oxford.

Blakely, R. D. and Hrusa C.T. 1989. Inland aquaculture development handbook. Suffolk, Great Britain: St Edmundsbury Press Ltd.

Boehlje, M.D. and Eidman, V.R. 1984. Farm management. John Wiley and Sons, New York.

Bodvin, T., Indergaard, M., Norgaard, E., Jensen, A. and Skaar, A. 1996. Clean technology in aquaculture –A production without waste products? Hydrobiologia 326/327: 83-86.

Botes, L., Thompson, G. and Louw R. 2006. Benchmarking survey of the South African aquaculture (Marine and Freshwater) sector. AISA report.

Braaten, B. 1992. Impact of pollution from aquaculture in six Nordic countries. Release of nutrient, effects, and waste water treatment. Aquaculture and the Environment. EAS Special publication No 16. Gent, Belgium.

Bray, R.N. 1979. Dredging: A handbook for engineers. Edward Arnold Ltd. London

Britz, P.J., Lee, B. and Botes, L. 2009. AISA 2009, Aquaculture Benchmark Survey. Primary Production and Markets. A report for the Aquaculture Institute of South Africa and Swiss contact, produced by –Environ-Fish Africa (Pty) Ltd.

Burke. J., Brouwer. R., Clark.R., Geourgious. S. and Turner. K. 2004. Economic valuation of water resources in agriculture: From the sectoral to a functional perspective of natural resource management. FAO, Rome.

Buryniuk M, Petrell R.J, Baldwin S and Victor Lo K. 2006. Accumulation and natural disintegration of solid wastes caught on a screen suspended below a fish farm cage. Agriculture Engineering 35: 78-90.

Carson, R.T. 2000. Contingent Valuation: User's Guide. Environmental Science Technology. 34:1413-1418. Available at: http//pubs.acs.org [accessed 25 February 2009]

Casalduero, F.G. 2003. Intergrated systems. "Environmentally clean" aquaculture. Universidad de Alicante, Campus de S. Vicente de Raspeig, Spain.

Chen, H.W., Chang, N.B. and Shaw, D. 2005. Valuation of in-stream water quality improvement via fuzzy contingent valuation method. Stock Environment Res Risk Asess, Vol 19: 158-171

Chopin, T., Robinson, S.M.C., Troell, M., Neori, A., Buschmann, A.H. and Fang, J. 2008. Multi-trophic integration for sustainable marine aquaculture. Ecological Engineering. Vol. 3. Elsevier, Oxford, 3: 2463–2475.

Cripps, S.J. and Beirgheim, A. 2000. Solids management and removal for intensive land based aquaculture systems, aquaculture Engineering 22, 33-56, Ullandahang, N-4091 Stavanger, Norway.

Croomey, C.J., Nickell, T.D. and Black, K.D. 2000. DEPOMOD—modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211–239.

Davenport, J., Black, K., Burnell, G., Cross, T., Culloty, S., Ekaratne, S., Furness, B., Mulcahy, M. and Thetmeyer, H. 2003. Aquaculture: The Ecological Issues. Blackwell Science Ltd., Malde, Oxford, Melbourne, Berlin, 89.

DEAT (Department of Environment Affairs and Tourism). 2006. [www.deat.co.za accessed on 13 June 2009]

DEAT (Department of Environment Affairs and Tourism). 1998a. Marine living resources Act 1998 (Act No 18 of 1998).Republic of South Africa Government gazette. www.deat.co.za [accessed on 17 June 2009].

DEAT (Department of Environmental Affairs and Tourism). National Environmental Management Act 107 of 1998b. www.deat.co.za [accessed on 14 June 2009].

DEAT (Department of Environmental Affairs and Tourism). 2004. National environmental management: Biodiversity Act (Act no 10 of 2004), Alien and Invasive species, regulation 2008. www.deat.co.za [accessed on 17 June 2009].

Division of Aquaculture, of University of Stellenbosch. 2005. Development of Small-Scale Farming systems: Western Cape, Annual report 2004/2005, Division of Aquaculture on behalf of “Hands-On Fish Farmers Co-operative”, University of Stellenbosch

Dixon, A.J., Richard, L.F.S., Carpenter, A.R. and Sherman, P.B. 1994. Economic analysis of environmental impacts.

Du Plessis, D. 2007. Impacts of aquaculture on the farm dam ecosystem and its use as a multipurpose resource, implications for irrigations. Msc. University of Stellenbosch.

DWAF (Department of Water Affairs and Forestry). 1996a. South African Water Quality Guidelines (1st edition). Volume 1, Domestic Use; CSIR Environmental Services, Pretoria, Republic of South Africa

DWAF (Department of Water Affairs and Forestry). 1996b. South African Water Quality Guidelines (2nd edition). Volume 2, Livestock; CSIR Environmental Services, Pretoria, Republic of South Africa

DWAF (Department of Water Affairs and Forestry). 1996c. South African Water Quality Guidelines (3rd edition). Volume 4, Irrigation; CSIR Environmental Services, Pretoria, Republic of South Africa.

DWAF (Department of Water Affairs and Forestry). 1996d. South African Water Quality Guidelines (4th edition). Volume 6, Agricultural Use: Aquaculture; CSIR Environmental Services, Pretoria, Republic of South Africa.

DWAF (Department of Water and Forestry Affairs). 1998. National Water Act, no 36 of 1998. www.dwaf.co.za [accessed on 26 June 2009].

DWAF (Department of Water and Forestry Affairs). 2008 www.dwaf.co.za. Dams in South Africa.

Enell, M. and Ackefors, H. 1991. Nutrient discharges from aquaculture operations in Nordic countries into adjacent areas. ICES, C. M. MEQC.

Enell, M., and Lof, J. 1984. Environmental impact of aquaculture: sediment and nutrient loadings from fish cage culture farming. Vatten, 39: 364–375.

Environment Australia, 2001. Australian emission technique manual for aggregated emissions from temperate water Finfish Aquaculture. Australia.

Ervik, A., Samuelsen, O. B., Juell, J. E., Sveier, H., 1994. Reduced environmental impact of antibacterial agents applied in fish farms using the Lift-up feed collector system or a hydroacoustic feed detector. Diseases of Aquatic Organisms, 19, 101-104.

Food Agriculture Organisation (FAO). 2004. Global aquaculture output outlook. An analysis of production forecasts to 2030. http://www.fao.org.ez.sun.ac.za/fishery/ [accessed 26 February 2009]

Food Agriculture Organisation (FAO). 2005. Fisheries resources: Trends in Production, utilisation and trade. http://www.fao.org.ez.sun.ac.za/fishery/ [accessed 26 February 2009]

FAO. 2006a. The state of world fisheries and aquaculture — 2006 (SOFIA): Trends in Production, utilisation and trade : Part 1, Food and agriculture organization of the United Nations, Rome (2007) ISBN 978-92-5-105568-7, Available at: http://www.fao.org.ez.sun.ac.za/fishery/ [accessed 26 February 2009]

FAO. 2006b. The state of world fisheries and aquaculture — 2006 (SOFIA): Selected issues in Fisheries and Aquaculture: Part 2, Food and agriculture organization of the United Nations, Rome (2007) ISBN 978-92-5-105568-7, Available at: http://www.fao.org.ez.sun.ac.za/fishery/ [accessed 26 February 2009]

FAO. 2007. The state of world fisheries and aquaculture — 2006 (SOFIA), Food and agriculture organization of the United Nations, Rome (2007) ISBN 978-92-5-105568-7, Available at: http://www.fao.org.ez.sun.ac.za/fishery/ [accessed 26 February 2009]

Foy, R.H. and Rosell, R. 1991. Loadings of Nitrogen and Phosphorus from a Nothern Ireland farm. Aquaculture (96).

Geohive. 2009. Population growth and projections to 2050 www.geohive.com [accessed on 25 June 2009)

Ghosh, S.K. 2000. Planning for marine cage fish farming following coastal zone management program- Technical options, Msc thesis, University of Hull, UK.

Gittinger, J.P. 1972. Economic analysis for agricultural projects. U.S.A: International Bank for Reconstruction and Development, John Hopkins University press, Baltimore

Guo, L and Li, Z. 2003. Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China. Aquaculture 226, 201–212.

Hafez, F.A.F. 1995. Diets with varying protein content 11, 17 or 25% on tilapi, carp and mullet. Egyptian Journal of Agriculture research.

Hall, P.O.J., Anderson, L.G., Holby, O., Kolberg, S., Samuelsson, M.O. 1990. Chemical fluxes and mass balances in a marine fish cage farm: I. Carbon. Mar. Ecol. Prog. Ser. 61.

Halwell, B. 2008. Farming Fish for the Future; World Watch Report 178. Danvers MA, U.S.A. World Watch Institute.

Hanemann, W. M. 1985. "Some Issues in Continuous- and Discrete-Response Contingent Valuation Studies. Northeast Journal of Agricultural and Resource Economics. Vol. 14, No.1:5-13.

Hanemann, W.M. 2005. The economic conception of water. Chapter 4. University of Carlifonia, Berkeley. U.S.A.

Hartwick, J.M. and Olewiler, N.D. 1998. The Economics of Natural Resource Use. 2nd edition. Reading: Addison Wesley.

Hayes, M.K., Tyrell, T.J. and Anderson, G. 1992. Estimating the benefits of water quality improvements in the Upper Narraigansett Bay. Marine resource Economics Journal, Volume 7:75-85). Rio de Janeiro. Brazil.

Heinrichsen, E. 2007. Guideline to the authorisation requirements for aquaculture in the Western Cape: Division of Aquaculture, Stellenbosch University Report. Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town, South Africa.

Hoffman, L. 1990. Aquaculture 1990: Proceedings of a joint symposium convened by the aquaculture association of South Africa and the University of Stellenbosch. Pretoria, South Africa, Aquaculture Association of South Africa.

Islam, M. S. 2005. Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis toward model development. Marine Pollution Bulletin. 50, 48–61.

Jacobsen, T. 1997. “Sediment problems in reservoirs- Control of sediment deposits”. Doctoral Thesis. Department of Hydraulic and Environmental Engineering, NTNU, Trondheim, Norway.

Karaan, M. and Rossouw, S. 2004. Baseline assessment of the fishing and aquaculture industry in the Western Cape. Department of Agriculture Economics, University of Stellenbosch.

Karaan, M. 2005. Trends issues, repositioning strategies and policy levers, Western Cape microeconomic strategy project, Fisheries and aquaculture Part II, University of Stellenbosch.

Leedy, P.D. 1997. Practical research: Planning and Design, 6th edition. U.S.A.: Macmillan Publishing Company.

Leyva, C.J. and Sayachi, S. 2005. Economic valuation of water. Willingness to pay analysis with respect to tropical fruit production in South Eastern Spain. Spanish Journal of Agriculture Research, Vol 3:25-33.

Lupatsch, I., Katz, T. And Angel, D.L. 2003. Assessment of the removal efficiency of fish farm effluents by grey mullet: A nutritional approach.

Maleri, M. 2007. Site selection and production performance of rainbow trout (*Oncorhynchus mykiss*) cage operations in small farm reservoirs: The Western Cape experience, South Africa. Department of Genetics, Division of Aquaculture, Stellenbosch University.

Masser, P.M. 2007. Cage culture: Site selection and water quality. Auburn University, SRAC, Oklahoma Cooperative Extension.

Miller, D. and Semmens, K. 2002. Waste Management in Aquaculture: Agriculture Economics and resource economics program, Division of Resource Management, College of Agriculture, Forestry management and Consumer sciences, Virginia, University.

Mitchell R.C. and Carsons R.T. 1989. Using Surveys to Value Public Goods. Contingent Valuation Method, Resources for the Future, Washington DC.

Muir, J.F., Brugere, C., Young, J.A. and Stewart, J.A. 1999. The solution to pollution? The value and limitations of environmental economics in guiding aquaculture development, Aquaculture Economics and Management, 3(1): 43-47.

Nhan, D.K., Verdegem, C.J.M., Binh, T.N., Duong L.T., Milstein A. and Verreth, J.A.J. 2008. Economic and nutrient discharge tradeoffs of excreta-fed aquaculture in the Mekong Delta, Vietnam. Agriculture, Ecosystems and environment Journal, 124:259-269 available at http.//.www.sciencedirect.com [accessed on 14 June 2009]

Oberholster, J.H. 2005. An investigation into the long-term sustainability of small scale aquaculture systems in the Western Cape of South Africa. Msc Thesis, University of Stellenbosch.

Partridge, G.J., Sarre, G.A., Ginbey, B.M., Kay, G.D., Jenkins, G.I. 2005. Finfish production in a static, inland saline water body using a Semi Floating Tank System (SIFTS), WA, Australia, Blackwell scientific Publications Ltd.

Perry, C.J., Rock, M. and Seckler, D. 1997. Water as an economic good: A solution, or a problem? Research Report 14. Colombo, Sri Lanka: International Irrigation Management Institute.

Phillips M.J. and Silva S.S. 2007. FAO Fisheries Technical Paper; (498), Rome: Food and Agriculture Organization of the United Nations (FAO), 21-48.

Phillips, M.J., Beveridge, M.C.M. and Ross, L.G. 1985. The environmental impact of salmonid cage culture on inland fisheries: present status and future trends. Journal of Fish Biology 27: (Suppl. A), 123–127.

Pillay T.V.R. 2004. Aquaculture and the environment. 2nd edition. Oxford UK. Blackwell Publishers.

Pillay T.V.R and Kutty, M. N. 1993. Aquaculture: Principles and Practices. 2nd edition, Oxford. Fishing news book.

Pillay T.V.R. and Kutty, M. N. 2005. Aquaculture: Principles and Practices. 3rd edition, Oxford. Blackwell Publishers.

Portney, P.R. (1994). The contingent valuation debate: Why economists should care. Journal of Economic Perspectives, 8: 3–17.

Prugnin, Y., Shilos and Mires, D. 1975. Grey mullet; A component in Polyculture in Israel. Aquaculture: 291-298.

Prugnin, Y. and Hyper, B. 1981. Commercial Fish Farming, Canada. John Wiley and Sons Inc.

Rouhan, Q.A., and Britz P.J. 2004. Contribution of aquaculture to rural livelihoods in South Africa: A baseline study .Water Research Commsison Report. Department of Itchtology and Fisheries Sciences, Rhodes University, Grahamstown, South Africa.

Salie K., and Van Stade, J., 2004. Small-scale fish farming in the Western Cape Province. Ten years of Aquaculture as a Socio-economic development Model. Presentation.

Salie, K., Resoort, D. and Du Plessis, D. 2008. Training manual for small-scale rainbow trout farmers in net cages on irrigation dams: water quality, production and fish health. Division of aquaculture, University of Stellenbosch, South Africa

Sangroula, P.D. 2007. Sediment management for sustainability of storage projects in Himalayas. A case study of the Kulekhani reservoir in Nepal. Presented at International conference on Small – Hydro power- Hydro Sri Lanka, 22-24 October 2007.

Shepherd, J. and Bromage, N. 1988. Intensive Fish Farming. Oxford, London. Blackwell Scientific Publications Books, 404 pp.

Shipton, T. and Britz, P.J. 2007. A Study on the Status of Aquaculture Production and Trade in South Africa. Volume 1: Industry Status and Diagnostic Report. A report for the Department of Trade and Industry produced by Enviro-Fish Africa (Pty.) Ltd.

Shpigel, M., Neon, A., Popper, D.M., and Gordhin, H. 1993. A proposed model for environmentally clean land based culture of fish, bivalves and seaweeds. Aquaculture, 117:115-128.

Skaar, A., Bodvin, T. 1993. Full-scale production of salmon in floating closed systems. Balkema, Reotterdam.

South African Constitution of 1996. Republic of South Africa government gazette. www.deat.co.za [accessed on 17 June 2009].

StatSoft Inc. 2008**.** STATISTICA (data analysis software system), version 8. www.statsoft.com

Stigebrandt, A., 1999. Turnover of energy and matter by fish—a general model with application to salmon. Fisken og Havet 5, 29 pp.

Sutherland and Walsh . 1985. Value of preserving water quality in the Flathead River basin, Montana, USA before actual degradation due to coal mining activity in the region. USA.

Tarcon, A.G.J and Forster, I.P. 2003 Aquafeeds and the environment: Policy implications Aquaculture; 226 (1/4), Amsterdam: Elsevier Science B.V., 2003, 181-189 Abstract:

The Brundtland report. 1987. Our Common Future: Report of the World Commission on Environment and Development United Nations.

The Standard Bank of South Africa Limited. 2005. Finance and farmers: A financial management guide for farmers.

Troell, M., Halling, C., Neori, A., Buschmann, A.H., Chopin, T., Yarish, C. and Kautsky, N. 2003. Integrated mariculture: asking the right questions. Aquaculture 226: 69–80.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A.H. and Fang, J.G. 2009. Potential of intergrated multi-trophic level (IMTA) in marine offshore systems. Aquaculture 297: 1-9. [Electronic; www.elsevier.com/ locate/aqua-online; accessed on 21 August 2010]

Vollenweider, R.A. 1968. Scientific Fundamentals of the eutrophication of lakes and flowing water with particular reference to nitrogen and phosphorous as factors in eutrophication. Technical Report DASISU/68-27. OECD, Paris.

Weston D.P., Phillips M.J. and Kelly, L.A. 1996. Environmental impacts of salmonid culture. Chapter 16 in: Principals of Salmonid Culture. Developments in Aquaculture and Fisheries Science 29: 919-967.

Whirtmash, D.J. Cook, J.E. and Black, K.D. 2006. Searching for sustainability in aquaculture. An investigation into the prospects for an intergrated salmon-mussel production system. Marine Policy 30, 293–298.

Whisson, G.J. 2000. Investigations into the commercial polyculture of Cherux tenuimanus and Bidyanus bidyanus. Ph.D Thesis. Curtis University of Technology.

Wurts, B. 2010. Sustainable aquaculture. The changing horizon. Presentation. Kenturcky University. www.ca.uky.edu/wkrec/WurtsLitpage.htm [accessed on 01/09/10]

Young RA. 1996. Measuring economic benefits of water investment and policies. The World Bank, Washington.

Young, R.A. 2005. Determining the economic value of water: Concepts and methods. Washington, U.S.A. Resource for the future.

**ANNEXURES**

# Western Cape small scale net cage aquaculture systems survey 2010

**INTRODUCTION**

My name is ..................................................................................from the University of Stellenbosch. I am carrying out research on aquaculture in the Western Cape focusing on net cage aquaculture producers and how they are dealing with the problem of change in water quality in dams due to nutrient loading in water bodies. The aim of this study is to gather information on how net cage producers are dealing with the problem of accumulation of organic waste that might have adverse effects on aquaculture and other uses of the water from the dam. The study also aims to identify mechanical methods that can be used by net cage fish producers to remove waste and possibly their effectiveness with the aim of comparing them with methods that are being used in other countries to deal with the problem of organic waste accumulation. The results of study will help net cage producers find the most cost effective mechanical methods that can be used to remove the waste. The results of the study will also help farmers maintain good water quality in dams and produce high quality fish, hence better prices, especially when trading in markets where there is now a high degree of awareness concerning environmental issues and sustainability of production systems.

**6.9 Confidentiality**

First let me begin by saying that most of the questions have to do with **your** knowledge and experience about aquaculture production as well as your opinions on the development of aquaculture industry, and there is no right or wrong answers. This interview is completely confidential; your name will never be associated with your answers in the report and only aggregated data will be used in the report. I hereby certify that this is an honest interview taken in accordance with my academic needs only.

**Date of interview...............................................** **Interviewer..................................................................................**

## 1. BACKGROUND INFORMATION

1.1 General information

| | |
|---|---|
| Name of aquaculture facility/company /project | |
| Contact details of aquaculture facility | Physical address..........................................................................................................................................<br>..........................................................................................................................................<br>..........................................................................................................................................<br>Postal address..........................................................................................................................................<br>..........................................................................................................................................<br>Telephone no..........................................................................................................................................<br>Cell no..........................................................................................................................................<br>Fax no..........................................................................................................................................<br>Email address<br>.......................................................................................................................................... |
| Distance of closest town | Km Town |
| Name of respondent | |
| Position of respondent in the business | |

1.2 What is the organizational form of the aquaculture farm (**indicate your answer by marking with a X**).

| Private company | Closed corporation | Sole proprietor | Cooperative | Trust | Public company | Other, specify |
|---|---|---|---|---|---|---|
| | | | | | | |

1.3 How many years has the aquaculture enterprise been operational?

| Less than 1year | 1-5years | 6-10years | 11-15years | 16-20years | 21-25years | More than25 years |
|---|---|---|---|---|---|---|
| | | | | | | |

1.4 Is the aquaculture enterprise operating at full capacity Yes ☐ No ☐

1.5 If your answer to 1.4 is "No" indicate the percentage capacity at which the aquaculture enterprise is operating at?

| 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

1.6.1 Who funded the initial capital of the aquaculture enterprise?

| Self | Contribution from members | Personal/Company loans | Third party | Other, specify |
|---|---|---|---|---|
| | | | | |

1.6.2 If the initial capital of the project was funded from more than one financial source indicate percentage contribution of each source.

| Self | Contribution from members | Personal/Company loans | Third party | Other, specify |
|---|---|---|---|---|
| | | | | |

1.6.3 If the project is funded by a third party(s), name them

..........................................................................................................................................................................................................................

..........................................................................................................................................................................................................................

1.7 Indicate percentage contribution of the following financial sources to the running costs of the project?

| Self | Personal/Company loans | Third party | Other, specify |
|---|---|---|---|
| | | | |

**2. PRODUCTION INFORMATION**

2.1 When did the aquaculture enterprise start on this farm? ..........................................................................................................................................

2.2 Has it been in operational since then Yes ☐ No ☐

2.3. If answer to the above question 2.2 is “No” give details of what happened when it stopped working.

.......................................................................................................................................................................................................................................

.......................................................................................................................................................................................................................................

.......................................................................................................................................................................................................................................

2.4 What method(s) of culture do you practise?

| | |
|---|---|
| Monosex | |
| Monoculture | |
| Poly culture | |
| Intergration of fish and livestock | |
| Aquaponics | |
| Other specify | |

2.5 How would you describe your scale of aquaculture operations?

| | | | |
|---|---|---|---|
| Large scale commercial<br>(>R5m pa turnover) | Small scale commercial<br>(<R5m per annum turnover) | Small scale food security(community project/cooperative) | Other,<br>specify |

2.6 Which business operations are included in your aquaculture business?

| | | |
|---|---|---|
| Spawning | Growing out | Grading |
| Fry/Rearing | Processing | Packing |
| Distribution | Other, specify | |

2.7 List fish species that are kept on the net cage enterprise. .......................................................................................................................................................

.......................................................................................................................................................................................................................................

2.8.1 Which method(s) of production does the business employ?

| | | | |
|---|---|---|---|
| Basket | | Recirculation | |
| Net Cages | | Tanks | |
| Long line | | Pump ashore | |
| Racks | | Ponds | |
| Rafts | | Raceways | |
| Trays in Ponds | | Circular ponds | |
| Earth ponds | | Urban  ponds | |
| Glass fish tanks | | | |
| Other, specify | | | |

2.8.2 How many net cage systems are in place.....................................................................................?

2.8.3 Indicate size dimensions

| | Net cage 1 | Net cage 2 | Net cage 3 | Net cage 4 | Net cage 5 |
|---|---|---|---|---|---|
| Surface area | | | | | |
| Depth | | | | | |
| Volume | | | | | |

2.9.1 Specify the net cage production and average unit prices for the following species for 2008/09 and 2009/10 production periods.

| | Rainbow trout | | Tilapia | | Sea bass | | Other species | |
|---|---|---|---|---|---|---|---|---|
| | Quantity in kg | Price per kg | Quantity in kg | Price per kg | Quantity in kg | Price per kg | Quantity in kg | Price per kg |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Production for year 2008/09 | Grade 1 | | | | | | | |
| | Grade 2 | | | | | | | |
| | Grade 3 | | | | | | | |
| | Other | | | | | | | |
| Expected Production for 2009/10 | Grade 1 | | | | | | | |
| | Grade 2 | | | | | | | |
| | Grade 3 | | | | | | | |
| | Other | | | | | | | |

2.9.2 Is it the same species originally kept when the project started? Yes ☐ No ☐

2.9.3 If your answer to question 2.9.2 is "No", why are the original species no longer kept?
..........................................................................................................................................................................................................................
..........................................................................................................................................................................................................................
..........................................................................................................................................................................................................................

**3. MARKETING**

3.1Which of the following markets do you supply?

| Markets | | | | | | |
|---|---|---|---|---|---|---|
| | Species | Grades | Quantities in kg/year | Species | Grades | Quantities in kg/year |
| Local community | Rainbow trout | 1 | | Tilapia | 1 | |
| | | 2 | | | 2 | |
| | | 3 | | | 3 | |
| | | Other | | | Other | |
| Domestic Market | Rainbow trout | 1 | | Tilapia | 1 | |
| | | 2 | | | 2 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 3 | | | 3 | |
| | | Other | | | Other | |
| Export | Rainbow trout | 1 | | Tilapia | 1 | |
| | | 2 | | | 2 | |
| | | 3 | | | 3 | |
| | | Other | | | Other | |
| Own consumption and labourers | Rainbow trout | 1 | | Tilapia | 1 | |
| | | 2 | | | 2 | |
| | | 3 | | | 3 | |
| | | Other | | | Other | |

3.2 Is the fish processed in any way? Yes ☐ No ☐

3.3 If the answer to 3.2 is "Yes", what percentage is usually sent for processing?

| Percentage for processing | On-farm processing | Elsewhere |
|---|---|---|
| | | |

3.4 How many months of the year is the fish farm able to produce fish ........................................................................................................................................

3.5 What is the annual sales/gross income from the net cage enterprise?

| Less than R10 000 | R10001-R20000 | R20001-R30000 | R30001-R40000 | R40001-R50000 | More than R50000 |
|---|---|---|---|---|---|
| | | | | | |

**4 HUMAN RESOURCES**

4.1 Indicate the number of employees employed on the farm.

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | Farm | Aquaculture | Net cage | Farm | Aquaculture | Net cage |
| Fulltime | | | | | | |
| Part time | | | | | | |

| Total | | | | | | |
|---|---|---|---|---|---|---|

4.2 What are the remuneration rates for labour employed in net cage enterprise?

| | Financial remuneration rate (R) | In natura (specify) | In natura value ( R) |
|---|---|---|---|
| Full time (R/month) | | | |
| Part time (R/day) | | | |

4.3 How many part time workers do you employ for the net cage fish production season?

.............................................................................................................................................................................................................

4.4 Please indicate which months of the year do you employ part time workers for net cage enterprise?

| Jan | Feb | Mar | Apr | may | June | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|

4.5 Does the net cage project offer human resource and skills development to the workers? Yes ☐ No ☐

4.6 If answer to question 4.5 is "Yes", indicate the kind of training the workers have received and from where?

| | | |
|---|---|---|
| Mentorship | In-house | Outside |
| Training | In-house | Outside |
| Skills development | In-house | outside |

4.7 Do the workers involved in net cage farming need further training? Yes ☐ No ☐

4.8 What kind of training is required? ..........................................................................................................................................................

.............................................................................................................................................................................................................

.............................................................................................................................................................................................................

## 5 ENVIRONMENTAL ISSUES

5.1.1 How many dams are on the farm?........................................................................................................................................................................

5.1.2 How many of those dams are used for net cage aquaculture purposes? ………………………………………………………………………..........

5.1.3 What are the other uses of the water from the dams? ………………………………………………………………………………………….........

…………………………………………………………………………………………………………………………………………………………

…………………………………………………………………………………………………………………………………………………………

5.1.4 Are all the net cages located in one dam? Yes ☐ No ☐

5.1.5 Where is the "dam(s)" located in the river system?

| Within the river | Water channelled from the river | Estuary | Ocean | Other, specify |
|---|---|---|---|---|
| | | | | |

5.1.6 What happens to the outflow of water from the dam? ....................................................................................................................................

.....................................................................................................................................................................................................................

.....................................................................................................................................................................................................................

5.1.7 Is the dam visible to the general public? Yes ☐ No ☐

5.2 Please rate the importance of the following water quality parameters to the operation of your net cage aquaculture project?

| Parameter | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Ammonia concentration | | | | | |
| pH | | | | | |
| Phosphorus | | | | | |
| Dissolved oxygen | | | | | |
| Suspended solids in water | | | | | |

Rating 1=no importance 2=little importance 3=neutral 4=some importance 5= high importance

5.3 Are there any records kept on water quality? Yes ☐ No ☐

5.4 How often is the water sampled to check these parameters (parameters mentioned in question 5.2)? ..........................................................................................................

5.5 Has there been any notable change in the following parameters for the past year?

| Parameter | Yes | No | Do not know |
|---|---|---|---|
| Temperature (water) | | | |
| pH | | | |
| Ammonia concentration | | | |
| Algal bloom | | | |
| Organic matter | | | |

5.6 Is there any monitoring or water analysis from external people? Yes ☐ No ☐

5.7 If answer to question 5.6 is “Yes”, who are they and how often?

| Organisation: | Frequency: |
|---|---|

5.8 Was an environmental impact assessment (EIA) carried out before the project was initiated? Yes ☐ No ☐

5.9 Can you rate the importance of the following environmental issues to the operation of your aquaculture enterprise?

| Environmental issues | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Site selection | | | | | |
| Water quality | | | | | |
| Water pollution(effluent) | | | | | |
| Impact of species on environment | | | | | |
| Feed management | | | | | |
| Chemical use | | | | | |
| Disease management | | | | | |

Rating: 1= no importance 2= little importance 3=neutral 4= some importance 5=high importance

## 6. FARM INVENTORY

6.1 If aquaculture is practised on an agricultural farm, list the land use pattern for the whole farm.

| Farming activity | Crop | Total area (ha) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| Dry land field crops | | |
| | | |
| | | |
| | | |
| | | |
| Irrigated field crops | | |
| Natural pastures | | |
| | | |
| | | |
| | | |
| Irrigated cultivated pastures | | |
| | | |
| | | |
| | | |
| Dry land cultivated pastures | | |
| | | |
| | | |
| | | |
| | | |
| Dry land orchards | | |
| | | |
| | | |
| | | |
| Irrigated Orchards | | |
| Dry land vine yards | | |
| Irrigated vineyards | | |
| Other land, specify use. | | |
| | | |
| | | |

6.2 List the inventory of the net cage aquaculture enterprise.

| Inventory and costs of running a net cage aquaculture enterprise | | | | | | |
|---|---|---|---|---|---|---|
| Description | Current value (R) | % of capital/cost used for net cage | Replacement value(R/m$^2$) | Present age (years) | Lifespan (years) | Salvage value (R) |
| **Fixed Improvements** | | | | | | |
| Buildings: | | | | | | |
| Labour houses | | | | | | |
| Warehouse | | | | | | |
| Garage | | | | | | |
| Ponds | | | | | | |
| Net cages | | | | | | |
| Grading and processing rooms | | | | | | |
| Other, specify | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| **Movable Assets** | | | | | | |
| Pumps | | | | | | |
| Generators | | | | | | |
| Refrigerators | | | | | | |
| Aerators | | | | | | |
| Feed Dispensers | | | | | | |
| Vehicles | | | | | | |
| Other, specify | | | | | | |
| | | | | | | |
| | | | | | | |
| | **Costs (R)** | | | | | |
| **Fixed Costs** | | | | | | |
| Salaries & wages to administrative staff | | | | | | |
| Salaries of owner(s) | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Telephone, postage &office accessories | | | | | | |
| Travelling expenses | | | | | | |
| Auditing, legal & technical expenses | | | | | | |
| Insurance | | | | | | |
| Interest on debt & equity | | | | | | |
| Other, specify | | | | | | |
| | | | | | | |
| **Variable production costs** | | | | | | |
| **Directly allocatable costs** | | | | | | |
| Fingerlings | | | | | | |
| **Feeds** | | | | | | |
| Farm preparation and maintenance | | | | | | |
| Soyabean cake | | | | | | |
| Rice cake | | | | | | |
| Water Fees | | | | | | |
| Purchase of drugs & chemicals | | | | | | |
| Electricity and fuel | | | | | | |
| Grading & processing | | | | | | |
| Purchase of product containers & packing materials | | | | | | |
| Freight & transportation cost | | | | | | |
| **Variable Labour costs** | | | | | | |
| No of man hours per day | | | | | | |
| Wages in cash or kind | | | | | | |
| Salaries of Manager | | | | | | |
| **Indirect operational costs** | | | | | | |
| Maintenance &service of equipment | | | | | | |
| Running expenses | | | | | | |
| Other, specify | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Non-directly allocatable costs** | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| **Total Costs** | | | | | | |

6.3.1 Is the current net cage system a clean system? Yes ☐ No ☐

6. 3.2 If your answer to question 6.3.1 is "No", what is the problem? ..................................................................................................................................................

..................................................................................................................................................................................................

6.3.3 What are you doing at the present moment to improve the situation of accumulation of organic waste? ..........................................................................................

..................................................................................................................................................................................................

..................................................................................................................................................................................................

..................................................................................................................................................................................................

6.3.4 Are there any method(s) in place that you are using to remove organic waste from the net cage system? Yes ☐ No ☐

6.3.5 If your answer to question 6.3.1 is "Yes", can you list the method(s)? ..........................................................................................................................

…………………………………………………………………………………………………………………………………

…………………………………………………………………………………………………………………………………

6.3.6 Can you briefly describe how the method(s) operates? ..........................................................................................................................................

…………………………………………………………………………………………………………………………………

…………………………………………………………………………………………………………………………………

6.3.7 What is the organic waste removed being used for at the present moment? ..........................................................................................................................

..................................................................................................................................................................................................

..................................................................................................................................................................................................

6.3.8 What are the costs of method that is being used to remove organic waste released from net cage systems from the dam? (*If not included in question 6.2.*)

| Initial costs of putting in place the method | Current value | Replacement value | Present age | Life span | Salvage value |
|---|---|---|---|---|---|
| Fixed improvements for method | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Movable assets for method | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Fixed costs for method | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Variable costs for method | | | | | |
| | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

6.4.1 Have you ever heard about the Semi-Intensive Floating Tank System (SIFTS)? (Explanation of the system) Yes ☐ No ☐

6.4.2 How would you rate the SIFTS, Lift-up and intergrated systems as technology that effectively deals with the problem of organic waste and reduces environmental concerns from aquaculture?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

← Less effective More effective →

6.4.3 Can you rate your chances of using the system in future?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|

← Less likely more likely →

6.4.4 Your comments on SIFTS ..............................................................................................................................................................................

..............................................................................................................................................................................

..............................................................................................................................................................................

6.5 According to you, which of the following legislation do you think is important for development of sustainable aquaculture?

| | |
|---|---|
| National Water Act 1998 (Act no 36 of 1998) | |
| National Environment Management Act 107 , of 1998 | |
| National Environmental Management: Biodiversity Act2004(Act no 10 of 2004),Alien and invasive species Regulation,2008 | |
| Animal Improvement Act(Act No 62 1998) | |
| Animal diseases Act,(Act No 35 of 1984) | |
| Other, specify. | |

6.6 State any challenges that are faced by your aquaculture business in meeting the legislative requirements of the aquaculture industry?

..........................................................................................................................................................................................................................................

..........................................................................................................................................................................................................................................

..........................................................................................................................................................................................................................................

..........................................................................................................................................................................................................................................

6.7 Please rate the importance of the following regulatory issues for environment management in general.

| Regulatory instrument | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Best Management Practice guidelines | | | | | |
| Trout production manual | | | | | |
| Guideline to authorisation requirements for Western Cape | | | | | |
| Legislation, policy and acts | | | | | |
| Biodiversity regulations | | | | | |
| Sanitation programmes | | | | | |
| Veterinary programmes | | | | | |
| Coordination by sector body | | | | | |

Rating: 1= no importance, 2= little importance, 3= neutral 4= some importance 5= high importance

6.8 Please rate the following barriers to entry your project is currently facing in aquaculture operations.

| Barrier to entry | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Environmental regulatory requirements | | | | | |
| Site selection (zoning, leasing, discharge permit) | | | | | |
| Extension services | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Processing (SABS approval, public health issues, bans on export) | | | | | |
| Tariffs for imports(Protect domestic market) | | | | | |
| Permitting (time takes to issue, farming and capture of fish) | | | | | |
| Access to skilled labour | | | | | |
| Access to research and technology development | | | | | |

Rating: 1= no importance, 2= little importance, 3= neutral 4= some importance 5= high importance

6.9 Please rate the importance of the following government measure for your aquaculture project.

| Government measures | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Permitting | | | | | |
| Technology development and transfer | | | | | |
| Extension services | | | | | |
| Facilitate finance and investment | | | | | |
| Strategic plan for sector | | | | | |
| Infrastructure support | | | | | |
| Capacity building | | | | | |
| Promotion of aquaculture industry | | | | | |

Rating: 1= no importance, 2= little importance, 3=neutral 4=some importance, 5= high importance

**7 SECTOR DEVELOPMENT**

7.1 Which of the following are problems faced by your aquaculture business?

| Problem | Yes | No |
|---|---|---|
| Lack of fingerlings | | |
| Poor infrastructure | | |

| | | |
|---|---|---|
| Disease occurrence | | |
| Insufficient water | | |
| Poor water quality | | |
| Lack of feed | | |
| Poor feed management | | |
| Predator | | |
| Regulatory approvals | | |
| Financial support | | |
| Technical support | | |
| Information access | | |
| Market access | | |
| Other | | |

7.2 State any other problems or challenges you are facing in aquaculture.....................................................................................................................................

.....................................................................................................................................................................................................................

.....................................................................................................................................................................................................................

.....................................................................................................................................................................................................................

7.3 Further comments and suggestions ...........................................................................................................................................................................

.....................................................................................................................................................................................................................

.....................................................................................................................................................................................................................

THANK YOU FOR YOUR TIME AND COOPERATION

# APPENDIX 2

## QUESTIONNAIRE: VALUATION OF IRRIGATION STORAGE DAM WATER QUALITY IMPROVEMENT USING A CONTINGENT VALUATION METHOD (CVM) AFTER WATER POLLUTION CONTROL MEASURES ARE PUT IN PLACE

Name of aquaculture facility ..........................................................................................................................

**Hypothetical situation**

Hello, I'm................................................................ of the University of Stellenbosch. We are doing research in farming communities where there are net cage systems in farm irrigation storage dams in the Western Cape Province about how important it is to maintain good water quality in dams, considering that the water from dams is used for multiple purposes. Your views will be used to help us in designing water pollution control programmes that can be implemented to reduce nutrient loading and eutrophication of dam systems. There are several nutrients that end up in the irrigation dams that come from point sources and non-point sources that cause changes in the dam ecosystem. Pollution of dam systems causes changes in water quality that affects water uses such as fish production, irrigation, domestic uses, recreational activities and livestock watering. There are concerns that imbalances of certain nutrients in dam systems might cause eutrophication and affects suitability of using water for irrigation, recreation, fish production and for domestic uses (see attached pictures). In order to prevent the above mentioned problems there is need to put in place water pollution control measures to reduce nutrient loading in dam systems so that good water quality is maintained in dams. Maintenance of good water quality will result in production of high quality fish suitable for human consumption and maintenance of water of good quality that is transparent and suitable for domestic and recreational purposes. The aim of the study is to determine the value or benefits that society will gain from maintaining water of good quality in dams that is suitable for the main uses of the dam.

Most of the questions have to do with your attitudes and opinions, and there are no right or wrong answers.

This interview is completely confidential and your name will never be associated with your answers.

**Date of interview........................** **Interviewer…………………………………..**

## A. Household information

1. Name of respondent: ......................................................................................................................................

2. Relationship to household head (if not the household head)..................................................................................

3. Name of household head (if not the respondent)..........................................................................................................

4. Gender of respondent (**indicate by putting a tick in the appropriate block**):

Male ☐ Female ☐

5. Gender of household head (if not respondent) Male ☐ Female ☐

6. Age of respondent

| | | | | | |
|---|---|---|---|---|---|
| <20 years | 21-30 years | 31-40 years | 41-50 years | 51-60 years | 60 years+ |

7. Age of household head (if not the respondent)

| | | | | | |
|---|---|---|---|---|---|
| <20 years | 21-30 years | 31-40 years | 41-50 years | 51-60 years | 61 years+ |

8. Marital status of respondent:

| | | | | |
|---|---|---|---|---|
| Single | Married | Divorced | Widow | Widower |

9. Number of people in the household?

......................................................................................................................................................................

10. Are there any children under the age of 17 years in your household?

Yes ☐ No ☐

11. If your answer to question 10 is "Yes", how many children in the household are under the age of 17 years? ..........................................................................................................................................................................

12. How many of the children are still attending school at present? ...........................................................................

13. Highest level of education.

| | Respondent | Household head |
|---|---|---|
| Never went to school | | |
| Grade passed (if Matric not completed) | | |
| Matric | | |
| Post Matric qualification | | |
| Certificate | | |
| Diploma | | |
| Degree | | |
| Honours | | |
| Postgraduate | | |
| Other, specify: | | |

## B. Household Income

14. Income of respondent and total household income per month.

| | Respondent | Total household income |
|---|---|---|
| Less than R2 000 | | |
| R2 001-R4 000 | | |
| R4 001-R6 000 | | |

| | | |
|---|---|---|
| R6 001-R8 000 | | |
| More than R8 000 | | |

15. If there are any other non-cash benefits of the household received as payment from the farm specify: .................................................................................................................................................................
.................................................................................................................................................................

16. Usually how many kilograms of fish are consumed by the household per week? ........................................................

17. In what form is the fish that you usually consume?

| | | | | | |
|---|---|---|---|---|---|
| Fresh | Frozen | Canned | Smoked | Fish fingers | Other, specify: |

18. Besides fish, can you state other source(s) of animal protein (meat) that is consumed by the household? .................................................................................................................................................................
.................................................................................................................................................................

19. Usually how many kilograms of the following animal protein (meat) are consumed by the household per week?

| | |
|---|---|
| Beef | |
| Chicken | |
| Pork | |
| Mutton | |
| Other, specify: | |

20. Are you or any member of the household involved in the aquaculture project?

Yes ☐ No ☐

21. If your answer to 20 is "Yes", can you state your annual income from aquaculture?

| | |
|---|---|
| Less than R2000 | |
| R2001-R4000 | |
| R4001-R6000 | |
| R6001-R8000 | |
| More than R8 000 | |

22. What position in the aquaculture business do you hold or member involved in the business hold? .................................................................................................................................................................

23. Do you usually consume fresh water fish from the dam on this farm? Yes ☐ No ☐

24. If your answer to question 23 is "Yes", has there been any changes in fish eating habits or patterns by your household since aquaculture started on this farm?

Yes ☐ No ☐

## C. Environmental information

25. How many years have you been staying on this farm? ..........................................................................................

26. What are your main uses of water from the dam? .................................................................................................
.................................................................................................................................................................

27. Of the following water uses, indicate which ones are you using at present and indicate which uses you think water from the dam in your opinion is suitable for.

| | Use at present | Suitability | | |
|---|---|---|---|---|
| | | Yes | No | Rate on a scale |
| Domestic uses: drinking and cooking | | | | |
| Domestic uses: washing and bathing | | | | |
| Fishable-fish from the dam can be consumed without worrying about endangering health | | | | |
| Swimming | | | | |
| Recreational activities: boating or any other water activities | | | | |
| Irrigation purposes | | | | |
| Livestock watering | | | | |
| Other (specify) | | | | |

Scale: 1=dangerous 2=not acceptable 3=acceptable 4=good

28. Has the introduction of aquaculture in the dams changed your uses of water from the dam?

Yes ☐ No ☐

29. If your answer to question 28 is "Yes", can you explain which use(s) and how? ..........................................................

.............................................................................................................................................................

.............................................................................................................................................................

.............................................................................................................................................................

30. Have you been staying on this farm for five years or more?

Yes ☐ No ☐

31. If your answer to question 30 is "Yes", can you rate on a scale how has the water quality of the dam changed over the past five years?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

← Much worse Much better →

32. Do you think it's important to maintain good water quality in dams? Yes ☐ No ☐

33. If your answer for question 32 is "Yes", can you rate on a scale how important it is for an aquaculture farmer to maintain good water quality in irrigation dams.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

← Not important Very important →

34. Do you think enough is being done by the aquaculture farmer to maintain good water quality in the dams? .............................................................................................................................................................

.............................................................................................................................................................

## D. Willingness to pay (WTP)

35. *"Let us say the dam on the farm is the only source of water on the farm and you use the water from the dam for domestic purposes, recreational fishing, swimming and the water is also used for irrigation and aquaculture. Due to accumulation of waste from different sources, algal blooms (unwanted plants) grow inside the dam. Water quality inside the dam change from its current state to a state shown in the attached picture (taken from certain dams in South Africa (see Appendix 3)). Considering that you use the water from the dam for the above mentioned uses, how much will*

*you be willing to pay (contribute) annually towards putting in place measures that prevents water from the dam to change to a state similar to that shown on the picture and improve it to be suitable for mentioned uses"*

Yes ☐ No ☐

36. If your answer to question 35 is "No", can you give reasons why you are not in a position to pay for water quality improvement...........................................................................................................................................

...................................................................................................................................................................

.........................................................................................................................................................

*(If your answer to question 35 is "Yes", then please proceed to answer question 37)*

37. Considering that you use the water from the dam for the above mentioned uses and you require good quality of water for your uses, how much will you be willing to pay (contribute) annually towards putting in place measures that prevents water from the dam to change to a state similar to that shown on the picture and improve it to be suitable for mentioned uses". (SEE THE BIDDING CARD)

.........................................................................................................................................................

**BIDDING CARD**

**A set of bid values of Willingness to Pay (WTP) for water improvements associated with scenarios of water uses**

| Water quality improvement scenarios | From state shown on the pictures to state suitable for Fish, Irrigation, Livestock | From state suitable for Fish to Swimmable | Swimmable to a state suitable for domestic uses |
|---|---|---|---|
| **1** | **R15, R30, R40** | **R15, R30, R40** | **R15, R30, R40** |
| **2** | **R20, R40, R45** | **R20, R40, R50** | **R20, R40, R50** |
| **3** | **R25, R50, R60** | **R25, R50, R60** | **R25, R50, R60** |
| **4** | **R40, R60, R75** | **R60, R70, R80** | **R40, R60, R80** |
| **5** | **R60, R80, R90** | **R60, R80, R90** | **R60, R80, R90** |
| **6** | **R90, R100, R120** | **R90, R100, R120** | **R90, R100, R120** |
| **7** | **R130, R180, R200** | **R130, R180, R200** | **R130, R180, R200** |

*Note:*

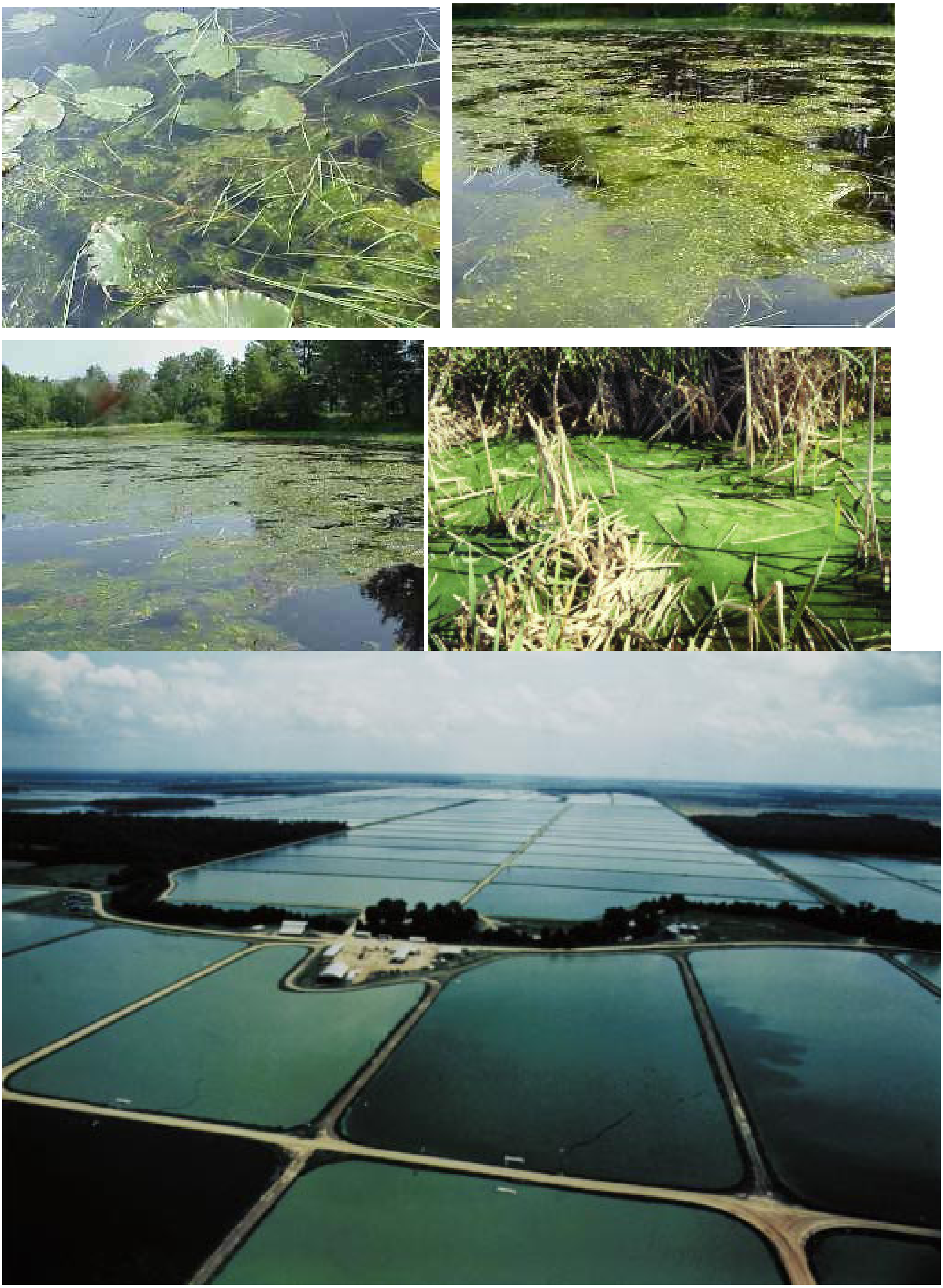
*1. Respondents will be randomly assigned a version of 3 bid values from the list of 7 versions in the table*

*2. The first number in parentheses is the starting WTP bid value; and the second value is asked if the answer to the first question is a **"YES"** or the third value is asked if the answer to the first question is a **"NO"***

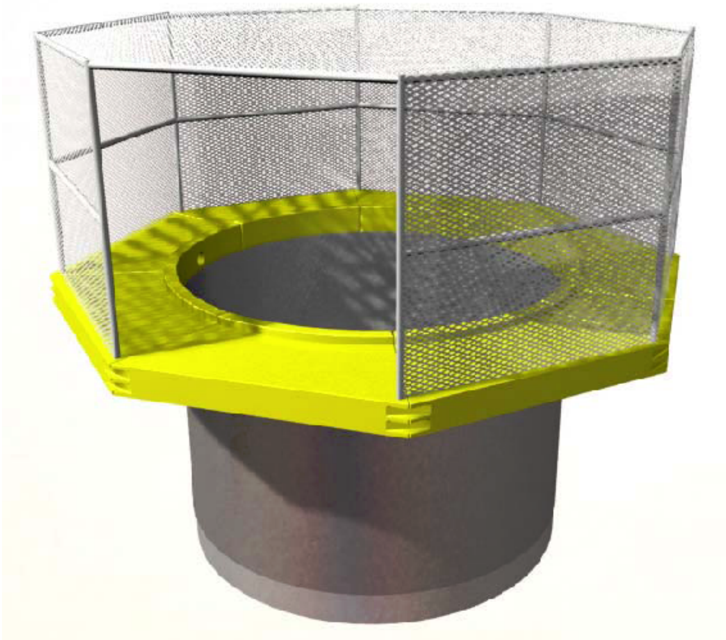
***Asking the question***

***Would you be willing to pay R30 annually to improve the water quality from the dam from a state shown on the pictures to a state that would be suitable for irrigation purposes and suitable for you to consume fish caught from the dam. If the answer is "Yes" are you willing to pay R40 annually to improve the water. If answer is still "Yes" then are you willing to pay R40 in the second version in the table? If answer to first question is "No" will you be willing to pay R20 annually for water improvement***

**APPENDIX 3**: Pictures showing algal blooms caused by eutrophication taken from dams in South Africa

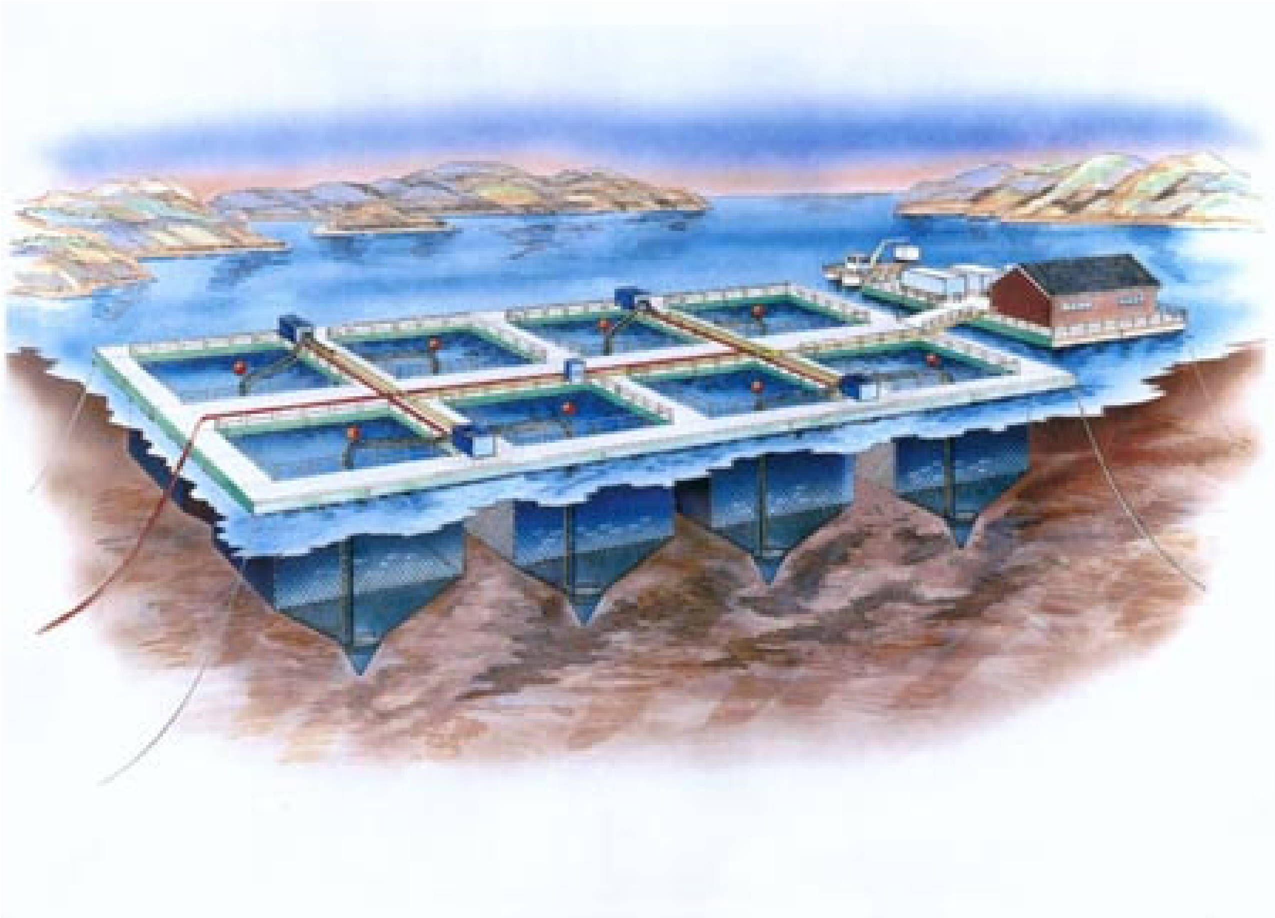


## APPENDIX 4: Semi-intensive floating tank system



Source: Partridge et.al. (2005)

APPENDIX 5: Net cage farm with a Lift-dead fish and waste collector



APPENDIX 6:  Small scale net cage farm in an irrigation dam in the Western Cape.